Journal
of the
British Interplanetary Society

Vol. 10, No. 6 XLIII November, 1951

THE ARTIFICIAL SATELLITE

An Introduction to the Symposium on Satellite Vehicles at the Second International Congress on Astronautics, London, 1951.

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The rapid development of rocket propulsion during the past two decades has brought home to the public, and to the hitherto sceptical scientific and technical world, the possibilities of constructing vehicles capable of escaping from the Earth or of attaining a stable orbit around our planet. Astronautical enthusiasts have been aware of these possibilities for much longer, but have in the past held their views at the cost of a considerable amount of ridicule. The position to-day has so altered that we expose ourselves to no great danger, in the form of derision from the pundits and "authorities," when we come together in this international discussion of the satellite vehicle or space station.

Indeed, one could go further and say that the present stage in the development of rocket flight is sufficiently far advanced to justify our embarkation upon a serious project directed in the first instance to the production of orbital vehicles, and later to the exploitation of these for the purpose of achieving interplanetary travel.

One government has already announced its intention of pursuing the development of satellite vehicles, though upon what scale we may only guess. In all probability this is being done for purely military purposes, and in so far as the military merits of the satellite vehicle are extremely dubious, it may well be that the pursuit of this project is not proceeding on a large scale. A military monopoly in this field would, in any case, be disastrous to the development of interplanetary flight, as indeed would be a military monopoly in any other form of transportation, and while one cannot deny the need for exploiting the rocket in the defence of our freedom, exclusive control of long-range rocket development by the military services is to be deplored.

It is important at the start of an international conference such as this that the need for setting up a project for the development of satellite vehicles under civilian control should be strongly emphasized. This is no longer a remote possibility to be talked about or written about, but one which should now be actively pursued in the laboratory, test bed and proving range. The performance of existing rocket motors is not far short of that required initially even by manned orbital vehicles, and ten or twenty years of vigorous development should eliminate the performance gap: there is no guarantee that military

development will lead to the right sort of rockets for space flight, since the requirements are not necessarily compatible. Indeed, the quickest course in the improvement of the rocket lies in the pursuit of an interplanetary project, since the requirements for this purpose are more exacting than for any other.

The uses to which a satellite vehicle might be put are sufficiently numerous to justify considerable expenditure on their development. Their value as scientific research stations and observatories would be beyond measure and in these days when considerable sums of the taxpayers' money are being diverted (and quite rightly so) into fundamental research, one might claim with considerable justification that the satellite vehicle is a worthy cause.

But the real value of the orbital vehicle lies in its importance as an essential springboard in the supreme adventure of interplanetary flight. This without doubt must be regarded as the main reason for our interest in the device, all other purposes being of secondary importance.

It is now generally agreed that the characteristic velocities required for vehicles making a return flight to the Moon or neighbouring planets without refuelling are too great to be achieved with existing methods of propulsion. If we take the easiest case, viz., a flight to the surface of our satellite, making full use of atmospheric braking when landing back on the Earth, we find that the characteristic velocity of the vehicle must exceed 20 km. per second. With the highest exhaust velocities at present available this would call for an effective mass-ratio greater than a thousand, which must be regarded as impossible. It is true that we now possess nuclear fuels, a kilogram of which would be sufficient to propel hundreds of tons of matter upon the journey, but the possibility of using them effectively for this purpose lies for the moment beyond the range of our science, though we may yet hope to make substantial improvements in rocket performance with their aid.

This gap between the desired and the available performance makes it necessary for us to break up any interplanetary flight into easier stages by introducing refuelling points upon the route. If we could find the necessary propellants for the return journey at our point of destination this would have a profound effect upon the problem, though it might not solve it entirely. However, such convenient "filling stations" do not occur in nature, and can only be set up as the result of an elaborate series of the flights which we seek to facilitate. This being the case we must choose an even more accessible refuelling point, and we are brought inevitably to consider the case of a station orbiting closely about the Earth.

A station orbiting about the Earth at an altitude of say 500 km. could be attained by a vehicle of characteristic velocity between 10 and 12 km./sec. Such a vehicle could furthermore return to the surface with the expenditure of only a small amount of propellant, sufficient to manoeuvre into an atmospheric braking trajectory. This velocity requirement is only about a half that required for the full lunar flight, so that the design of an orbital vehicle is a problem of a much lower order of magnitude.

The attainment of a stable orbit just outside the atmosphere is indeed no insurmountable task, even when considered in terms of present rocket performance. If, for example, we consider a rocket having an exhaust velocity

of 3 km./sec. (*in vacuo*), a performance which is by no means outside the range of existing propellants, we find that a mass-ratio in the region of 30–50 would be sufficient to achieve the orbit. This could be done in a three-step rocket, having an initial mass of about 300 tons for each ton of useful payload carried. At current prices this might amount to a propellant cost of *circa* £10,000 per ton of payload. (In more popular terms one might quote a single fare of say £5,000 to take a passenger to a space station!) The development costs involved in the project would, of course, be considerable, but a great deal of this would represent capital investment and various non-recurring expenses.

Thus rockets of present-day performance can form the basis for designing satellite vehicles, and there is no technical reason why an early start should not be made on a project to develop such vehicles. However, the fact that existing methods are good enough for achieving orbital flight does not establish their adequacy for bringing about interplanetary flight. If one considers, for example, the next step in a manned flight to the Moon, one finds that the vehicle going from the orbital station to the surface of the Moon and back to the station would require a characteristic velocity of 10 km. per second, a similar requirement to the satellite vehicle though the lower thrust requirements (since the vehicle would not have to struggle against Earth's gravitational field) would make it possible to obtain more favourable structural factors and higher payload ratios than in the latter case. Nevertheless, a manned flight to the Moon would make it necessary to assemble about a thousand tons of propellants and structural material in the orbit, if the second stage in the flight were to proceed with an available exhaust velocity of only 3 km. per second. If the satellite vehicles weighed a thousand tons at take-off they would need about 300 flights to complete this operation. Although this is by no means impossible, it cannot be regarded as a sound basis for sustaining interplanetary exploration, and some reduction is clearly desirable.

Thus the exploitation of the orbital refuelling station, while it improves considerably our chances of reaching the Moon and other planets, does not give us grounds for complacency about existing rocket performance. There is clearly a need for improved performance if we are to have economical space flight based on the use of orbital refuelling techniques. However, the required degree of improvement is much more reasonable than that which would be required in the case of the non-refuelling Lunar rocket. In the latter case an exhaust velocity greater than 10 km. per second would be required, while with orbital refuelling an exhaust velocity of half this value would be sufficient to bring interplanetary flight down to a reasonable economic level. This improvement might be achieved with chemical propellants, though it is more likely that some application of nuclear energy is required, in particular, an atomic rocket using water as the propellant mass.

One of the possibilities which might be opened up by the use of orbital space stations is that of using new methods of propulsion characterized by very high exhaust velocities at very low thrust. The most promising method, working on these principles, would be the ion rocket. In this device propulsion would be achieved by a beam of ions accelerated by electrical means, the ion beam taking the place of the exhaust jet of the conventional rocket. Exhaust

velocities of hundreds of kilometres per second could be obtained by this means, but they could only be obtained at the expense of having very low thrusts in view of difficulties of dissipating waste power. Consequently these machines could not propel vehicles against planetary gravitational fields, but they could drive vehicles operating between orbital stations at "milligee" accelerations. Adequate energy sources would of course be required, but these exist already in the form of nuclear fuels, although many people maintain alternatively that this could "all be done by mirrors"—using solar radiation.

The subject of the use of ion rockets as a means for propelling vehicles between satellite stations is dealt with very fully in the paper of Professor Lyman Spitzer, which will be read later in this colloquium, so it is unnecessary to enlarge upon the matter here. Suffice it to say that we have in the ion rocket a basis for bringing about interplanetary flight in an economic manner, since it provides us with the possibility of moving payloads from one orbital base to another with almost negligible expenditure of propellants. To take an example, we might consider an ion rocket operating between an Earth-satellite station and Deimos or Phobos. Assume, for example, that the rocket used iron as a source of propellant ions, and that it developed an exhaust velocity of $\sim$ 100 km. per second. This vehicle could make all the necessary velocity changes involved in going from the Earth-satellite orbit into a cotangent orbit between Earth and Mars and in going from this transit orbit into the orbit of Deimos or Phobos with a mass ratio of about 1·1, i.e., a 100-ton vehicle would require to carry little more than 10 tons of a propellant material which could be picked up easily almost anywhere in the solar system.

The ultimate place of the orbital space station in interplanetary flight would thus appear somewhat as follows. Space stations would circle all the most important planets and satellites. Normal rockets (conventional or nuclear-powered) would operate between the planetary surfaces and the space stations, while ion-rockets would ply between the space stations. The satellite vehicles would of course be supplied from their own planetary bases, but the space stations and ion rockets would probably be supplied from sources at low gravitational potential, i.e., surfaces of small satellites and asteroids. It would be very important at an early stage in the development of space flight to set up a supply base on our own Moon, manufacturing propellants and materials, since it would be far easier to supply an Earth-satellite station from the Moon than from the Earth.

In summary, we may say that the exploitation of the possibilities inherent in the satellite refuelling station gives us a clear basis for proceeding with the development of interplanetary flight. The steps which must be taken are as follows:—

(i) The development of satellite vehicles, based on existing methods of rocket propulsion.

(ii) The development of improved methods of propulsion (including nuclear rockets of conventional pattern, and ion rockets), in order to bring the cost of interplanetary exploration down to a reasonable level.

An early start is technically possible and extremely desirable.

INTERPLANETARY TRAVEL BETWEEN SATELLITE ORBITS

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ABSTRACT

An analysis is given of the performance to be expected of a rocket powered by nuclear energy, and utilizing an electrically accelerated ion beam to achieve a gas ejection velocity of 100 km./sec. without the use of very high temperatures in the propellant gases. While such a rocket would have much too low a thrust to take off from the surface of a planet, it would appear to be capable of travelling from a circular orbit about the earth to a circular orbit about any other planet in the solar system. Gases obtained from planetary atmospheres could be used for the propellant, and the only refuelling required from the Earth would be supplies for the crew and small amounts of fissionable material. Preliminary indications are that such a rocket could feasibly be constructed and operated at the present time.

I. Introduction

During the past decade much thought has been given to the problem of sending a rocket up to a circular orbit some three hundred miles above the earth, and thus creating an artificial satellite. It appears that this problem can be solved by present techniques. With the use of chemical fuels a multi-stage rocket designed to launch a man-made satellite now seems perfectly possible in principle, although much engineering development would be needed to realize this possibility in practice. The ratio of the take-off weight to the weight of the satellite would be large, probably several hundred or so, but not prohibitive.

The next step beyond an artificial satellite has seemed much more difficult. To travel from a close circular orbit around the Earth to the Moon and back or to another planet and back requires almost prohibitive amounts of fuel with conventional rockets. In theory, many Earth-launched rockets could be used, each one carrying fuel to one of several refuelling stations for an eventual interplanetary trip. However, the many analyses made of this technique indicate that a discouragingly large number of very large rockets would be required to make possible even one trip to the Moon and back. For a planetary trip the difficulties are even greater.

While the possible use of nuclear energy may revolutionize our concepts of space travel, the use of nuclear power simply to heat up the propellant gases from a rocket would not make interplanetary travel particularly feasible. It is well known that one of the chief limitations on a conventional rocket is the temperature which the rocket tubes can tolerate without melting or evaporating. A nuclear-powered rocket using heated propellant gases could not use a higher gas temperature than a chemically-powered rocket, and its only advantage would lie in the use of lighter propellant gases, with higher velocities at a particular temperature. A nuclear-powered rocket making use

A paper read to the Second International Congress on Astronautics in London, September 6, 1951.

of molecular hydrogen as propellant would need somewhat less propellant than would a conventional rocket using the best chemical fuels, but the gain would fall far short of the orders of magnitudes of improvement needed to make interplanetary travel feasible. Moreover, the rapid transfer of enormous quantities of heat from a uranium pile to a propellant gas offers difficulties that might well prove insuperable. We may conclude, as others have already done, that the use of nuclear power in an otherwise conventional rocket does not seem to provide an ideal solution to the problem of interplanetary flight, though it might be of use in the trip from the Earth's surface to a close satellite.

This entire picture changes if we shift our point of view and consider space ships which need not land on planets but instead travel from one circular orbit to another. To take off from the Earth and reach a satellite orbit requires not only an enormous amount of energy, but also requires that the energy be delivered in a very short time. A rocket designed to take off from the Earth's surface must obviously have a thrust greater than the rocket's weight, and this requires that the take-off period is short; i.e., the power, or energy per unit time, must be very great. A conventional chemical rocket is the only practical means yet found to produce such enormous powers without excessive weight.

For an interplanetary space ship, however, a large thrust is not required. Such a ship, travelling between circular orbits about different planets, can accelerate relatively slowly, and while the total amount of energy required is still large, the power needed may be reduced by about 1/100, and instead of the hundred thousand horse-power used in a large chemical rocket, a few thousand horse-power is sufficient. The present paper describes a low-thrust, low-power ship of this type, designed to travel from one planet to another, without ever landing. The several thousand horse-power needed is generated in a uranium or plutonium pile, converted into electrical energy, and used to accelerate a stream of ions by purely electrical means to a speed of about a hundred kilometres a second. Different components of this ship are discussed in the following sections, with the necessary mathematical analysis given in the appendices.

The ideas outlined here are probably not new; possibly the extensive literature on space flight contains some reference to a system similar to that proposed in the present paper. No search of the literature has been made.* The chief purpose of this paper is not to claim priority for any ideas but to focus attention on what promises to be the most practical means for interplanetary flight in the near future.

II. Power Supply

The power–weight ratio needed to give a ship an acceleration depends only on the acceleration itself multiplied by the velocity of the ejected propellant gas. As a reasonable acceleration we may take 0·3 cm./sec.^{2}, which would

* *I am much indebted to Dr. L. R. Shepherd for calling my attention to some earlier work along the present lines. Oberth in his book* Wege zur Raumschiffahrt *proposes a rocket propelled by an ion beam, powered by solar energy. The possible performance of an ionic rocket powered by uranium or plutonium has been considered by Shepherd and Cleaver,* Journal, B.I.S., *8, p. 59, 1949); their pessimistic conclusions regarding such a device result from their assumed acceleration of 0.01 gravities, some thirty times the acceleration assumed in this paper.*

make it possible to escape from a close circular orbit about the Earth in a few weeks and to reach Mars a few months later. The velocity of the ejected gas may be taken as 100 km./sec. A higher value would require more power, while a lower value would yield a less favourable mass ratio. With this choice of acceleration and gas velocity, the power needed is about a tenth of a horse-power per pound, as shown in Appendix 1. We shall consider a ship whose gross weight is about 10 tons, since this is probably the smallest-size ship that could carry a uranium or plutonium pile. The total useful power must therefore be roughly 2,000 horse-power. If an over-all efficiency of one-third is assumed in the conversion of heat into useful power, a heat source of 6,000 horse-power must be provided.

How can this power be produced? A normal pile weighs many hundreds of tons and could presumably generate much larger powers. For an interplanetary space ship one may envisage a pile constructed with U 235, the lighter isotope of uranium, or with plutonium, Pu 239. These materials are the ingredients of an atomic bomb, and a pile made with these fissionable materials could have a very much smaller size and weight than one using ordinary uranium. The use of atomic fission for power production is still in the development stage, but one may assume that within the next ten years the design and operation of a small pile, weighing about a ton and producing some 6,000 horse-power of heat, will become entirely practical. Such a pile would consume about 2 kilograms of U 235 or Pu 239 in a year of steady operation, and nuclear fuel for 50 years of continuous operation would weigh only 100 kilograms, or a tenth of a ton!

What about the dangerous effects of so much radio-activity on the crew aboard this ship? The usual pile is surrounded by concrete and lead, to shield personnel from the neutrons and gamma rays. Such shielding is very heavy, and would be practical only in an interplanetary ship whose size and weight were already very large. Thus, one could design and probably build a space ship weighing 10,000 tons, powered with a uranium pile weighing perhaps 1,000 tons, and generating two million horse-power of useful energy. Such a ship could carry thousands of people and vast supplies anywhere in the solar system, and could even navigate to other stars, though many generations would be born, grow up and die on shipboard before such a journey were complete. However, launching such a ship from the Earth's surface to a close circular orbit would be a tremendous undertaking. With the use of chemical fuels, such a launching would require a rocket of some million tons gross weight, an achievement that would seem far, far in the future.

Returning, then, to our smaller interplanetary ship, we still have the problem of how the personnel are to escape the hazards of nuclear radiation. The easiest way to achieve safety from neutrons and gamma rays is simply by distance. One may envisage the main interplanetary ship as a pilotless engine-room, with a light control car, containing the crew, attached by wires some 100 kilometres in length. Power and communications could be sent over the connecting wires, with probably also radio communication and an auxiliary power supply in the control car. Appendix 2 shows that at 100 kilometres from a pile generating 6,000 horse-power of nuclear energy, the flux

of neutrons and gamma rays would be down to a safe value. If a shorter towing distance were desired, the pile might be designed as a long thin cylinder, with the axis pointed at the control car, and some shielding provided at the end of the cylinder nearest the control car.

If the car containing the crew and control equipment weighed 2 tons, the wires pulling the car with an acceleration of 0·3 centimetres per second per second would be subject to a force of 1·2 pounds. With a safety factor of a hundred the two connecting wires need each have a diameter of only 0·02″ and would each weigh about 300 pounds, not an excessive contribution to the mass of the ship. Careful precautions would be needed to maintain tension on the wires at all times to avert sudden accelerations and breaking of the wires. There seems no reason why this technique could not be used, although so great a distance between passengers and power plant may seem somewhat unconventional. If repairs to the main ship became necessary during flight, the power could be turned off and the control car could be drifted up to the space ship.

III. Generation of Electrical Power

A uranium or plutonium pile generates power in the form of heat, and this must be converted into electrical energy. One may visualize a small pile, with heavy water used as a moderator, in which the heavy water is heated up, turned to steam, and used to drive a steam turbine. This turbine then drives a direct-current generator, whose output is used to accelerate the propellant gases, as discussed in the next section.

Since no problems of shielding of personnel are involved in the space ship, the design of such a system is somewhat simplified, but many problems of detail remain. The neutrons will produce nuclear transformations all through the ship, with possibly unfavourable results on the operation of the electrical and other equipment. The gamma rays will produce ionization in all materials, again creating problems of equipment performance and maintenance. Considerable research on such problems is presumably underway in connection with present piles, and one may hope that solutions to these problems will be available shortly. There appears to be no reason in principle why such problems cannot be solved.

If the radiation hazard to the ship itself can be overcome, two other problems remain. First, there is the matter of cooling. To operate a heat engine, the heat produced at a high temperature must be given up in a condenser at a low temperature, and the only way for the condenser in a space ship to lose this heat is by radiation. The rate at which a solid body radiates heat varies as the fourth power of the temperature. Thus we find ourselves in something of a dilemma. If the condenser temperature is made low, about room temperature, the rate of radiation is so low that impractically large radiating surfaces are required. If the condenser temperature is made very high, then the temperature at which the heat is generated must be even higher, and materials tend to melt or lose their strength, especially when submitted to nuclear bombardment. This subject is analyzed in Appendix 3, where the temperatures of heat input and heat output are taken to be 900° K. and 450° K. respectively,

or 1,160° F. and 350° F. With these temperatures a heat engine has an ideal efficiency of one-half, and at a pressure of about 10 atmospheres the steam will liquefy in the condenser. Even at this relatively high temperature, however, the radiating surface required is about a thousand square yards. One may visualize a thin fin some 30 yards square extending on one side of the ship, radiating the heat produced by the pile.

Secondly, there is the problem of the weight of all the material required to produce some 2,000 horse-power of useful electrical power. An over-all weight–power ratio of 10 pounds per horse-power is in the same general neighbourhood as the weight–power ratio for diesel-electric railroad locomotives and for bombing planes. It is not unreasonable to assume that about this same value can be achieved for an interplanetary space ship.

IV. Propulsion of Ship

It now remains to convert the electrical power, whose generation was discussed in the preceding section, into useful work. In particular, the only way a space ship can be propelled is by ejection of a stream of gases, and the electrical power must be used for this purpose. By use of electrostatic forces to accelerate a beam of ions, very high gas velocities can be achieved without the use of very high temperatures. The production of intense ion currents has been extensively studied in the last decade, and the acceleration of a space ship by an ion beam seems to offer no particular difficulties.

The electrical voltage to be applied depends only on the mass of the ion to be used and the velocity desired. The equations, given in Appendix 4, show that to accelerate nitrogen ions to a speed of 100 km./sec. requires a potential of 730 volts. Nitrogen is indicated as a propellant, since this gas is readily obtained from the Earth's atmosphere, and the ship can therefore obtain propellant gases in its circular orbit; this avoids the necessity of bringing tons of propellant up from the Earth's surface for every trip. Since nitrogen is probably also abundant in the atmospheres of Mars and Venus and possibly other planets, propellant gases could also be obtained at various points in the solar system.

At the relatively low voltage of 740 volts required to accelerate nitrogen ions, space-charge effects limit the total ion current that can be accelerated. Appendix 4 shows that an accelerating area of about 7 square yards would be needed to produce an ion beam of the necessary 2,000 amperes and 1,500 kilowatts. This result assumes that the accelerating voltage is applied over a distance of only a millimetre. Two fine-mesh wire screens, made with wires of very small diameter, could be placed this far apart and given the requisite potential difference. Thermionic emission from the wires in the outer screen could add electrons to the beam so that the ejected gases and the ship would remain electrically neutral.

It may be remarked that if the accelerating voltage were increased to a hundred thousand volts, the ion velocities would be about a thousand kilometres per second, and a space ship could in theory attain a speed of this order after about a hundred years of acceleration. At such a speed about a thousand years would be required to reach the nearest star.

V. Launching and Use of Ship

The preliminary analysis presented here indicates that there is every reason to believe that an interplanetary space ship could be built with essentially present techniques. Such a ship could not by itself land or take off on any major planet or satellite, although it could readily land on a small asteroid or on one of the tiny moons of Mars, where the small weight of the ship could easily be balanced by the rocket's thrust. However, the ship could proceed from a circular orbit about the Earth to a similar orbit about any other body in the solar system.

How could such a ship be used? Since we are all situated on the Earth's surface, a ship of this type could be employed only if some means for travelling up to a circular orbit were available. We have already indicated that with the use of chemical rockets this problem is, in principle, solved. One may envisage short-range chemical rockets, with a starting weight of at least several hundred tons, sending a final weight of about a ton up to a circular orbit, where contact would be established with an interplanetary ship.

Probably the most difficult problem of this sort would be the initial launching of the interplanetary ship itself. While a voyage of many hundred million miles in space could readily be achieved by this ship, ascent of the first few hundred miles to a circular orbit would definitely require a booster of some sort. In this case the booster would weigh initially some hundred times as much as the ship, or a few thousand tons. This is definitely a case where the first few hundred miles are the hardest, and in fact the design and construction of such a large "launching rocket" might well be more difficult than the design and construction of the long-range space ship.

Another problem, almost as difficult as that of the take-off, is that of landing. Air resistance seems the obvious way to slow down a ship returnng to the Earth's surface. However, a body in a circular orbit has a vast amount of energy, and disposing of all this energy by air resistance without vaporizing the material is no trivial problem. There are a number of ways in which glided flight down from a circular satellite might seem to be feasible. Since this subject is dealt with in another paper in this symposium it will not be discussed here.

One possibility in this connection should be noted, however. Gliders constructed for descending from a satellite will probably require wings and bodies of appreciable weight. It might be cheaper in the long run to fabricate these in space, from the nickel–iron presumably available on asteroids, rather than haul them up to the circular orbit by chemical rockets. An interplanetary spaceship could readily land on a small asteroid and might conceivably carry the tools necessary to fabricate out of the iron in the asteroid at least the wings needed; these might then be attached to the rockets shot up from the surface.

Landing on another planet would be more of a problem, since a chemical rocket with large quantities of fuel would presumably be needed for the return trip. Possibly such a rocket could be hauled up from the Earth's surface to the circular orbit without its fuel, and the gaseous fuel collected by long-range spaceships from the atmosphere of various planets—possibly oxygen

from the Earth and hydrogen or methane from Titan, the satellite of Saturn. All this material could then be glided down to the surface of Mars. After exploration of the planet, the chemical rocket could be assembled, and an ascent to a circular orbit made.

Evidently the nuclear-powered electrical rocket could open up many possibilities for interplanetary travel. Only the future can reveal to what extent these possibilities may be realized.

Appendices

1. Power–Weight Ratio

We consider the power consumed in an ideal rocket in which the atoms in the rocket jet have no random motion. Let N atoms per second, each of mass m, be propelled away from the rocket at a speed v_a. Then the total backward momentum imparted to the atoms per second will be Nmv_a; if M is the mass of the ship, and a its acceleration, then

$$Ma = Nmv_a \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (1)$$

The energy imparted to each atom is $mv_a^2/2$. Hence the power P, in watts, is given by

$$P = \frac{1}{2}Nmv_a^2.10^{-7} \quad .. \quad .. \quad .. \quad .. \quad .. \quad (2)$$

Combining equations (1) and (2) we have

$$P = \frac{1}{2}Mav_a.10^{-7} \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (3)$$

Equation (3) gives the power–weight ratio for a given acceleration and atomic velocity v_a. For an acceleration of 0·3 cm./sec.^{2}, sufficient to attain a velocity of 15 km./sec. in two months, and for a value of v_a equal to 100 km./sec., sufficient for a total velocity change of 30 km./sec. with a mass ratio of about 1·3, we find

$$\frac{P}{M} = 0{\cdot}15 \text{ watts/gram} \quad .. \quad .. \quad .. \quad .. \quad .. \quad (4)$$

corresponding to a weight–power ratio of 11 pounds per horse-power. Thus, for a ship with a mass of 10 tons, the power capacity must be roughly 2,000 horse-power, or about 1,500 kilowatts.

2. Radiation Shielding

We compute the distance at which personnel will be safe from the neutrons produced in a uranium or plutonium pile, generating 1,500,000 watts. With an ideal efficiency of one-half and an actual efficiency of perhaps one-third, the total heat generated will be three times the electrical power produced. Let N_n be the number of neutrons liberated per second. Since one neutron per fission must go to sustain the reaction,

$$N_n = \frac{3P(y-1)}{10^{-7}E_f} \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (5)$$

where y is the number of neutrons per fission, and E_f is the energy released per fission, in ergs. While precise values of y are not apparently available, this quantity is somewhat greater than unity. The energy E_f is about 3.10^{-4}. If none of the excess neutrons liberated were absorbed, the flux of neutrons F_n per square centimetre at a distance r centimetres would be given by

$$F_n = \frac{N_n}{4\pi r^2} \qquad (6)$$

If we combine these equations we find that at a distance of 100 kilometres from a reactor with an electrical power of $1{\cdot}5.10^6$ watts,

$$F_n = 1{\cdot}3.10^2(y-1) \text{ neutrons/cm.}^2 \text{ sec.} \qquad (7)$$

If $y - 1$ is about one, this value of F_n is about the safe dosage for continuous exposure to fast neutrons.* For comparison, a lethal dose within a short period would be 5.10^{11} neutrons per square centimetre. At the rate obtained from equation (7) about a hundred years would be required for a dose of this magnitude. It is well known that over a long period of time the human body can stand without any injury many small successive doses of radiation, which would be fatal if received all at once. Consideration of additional neutron absorption within the pile would presumably reduce the neutron flux even further.

The computation of the gamma-ray flux is somewhat more complicated. The lethal dosage of gamma rays corresponds to about the same flux of photons per square centimetre as the lethal dose of neutrons, in neutrons per square centimetre. Since one would expect the number of gamma rays and neutrons produced in fission to be roughly equal, one may conclude that at 100 kilometres the gamma-ray flux will also be below the safe limit. A more detailed analysis of gamma rays would be necessary for conclusive results, however, especially since the absorption of gamma rays within the pile will probably be less than the absorption of neutrons.

3. Problems of Cooling

The generation of electrical power by means of a heat engine requires that the heat produced at a temperature T_1 be conveyed to a "sink" at a temperature T_2. The ideal efficiency is $(T_1 - T_2)/T_1$. In interplanetary space the only way heat can be dissipated is by radiation, and the radiating surface A_r must be sufficient to radiate at the temperature T_2 the heat flowing to it. If Q represents the heat radiated per second, measured here in watts,

$$\frac{P}{Q} = z\left(\frac{T_1 - T_2}{T_1}\right) \qquad (8)$$

where z is the ratio of the actual efficiency of power generation to the ideal efficiency. The heat radiated per second from the surface, if we assume this is a perfect absorber, is given by

$$Q = \sigma A_r T_2^4, \qquad (9)$$

* *I am indebted for this figure to Dr. L. R. Shepherd, who kindly pointed out an inaccuracy in an early version of this paper.*

where

$$\sigma = 5{\cdot}7.10^{-12} \text{ watts/cm.}^2 \text{ deg.}^4 \text{ sec.} \quad .. \quad .. \quad .. \quad (10)$$

Combining equations (8) and (9) we obtain for A_r,

$$A_r = \frac{PT_1}{\sigma z(T_1 - T_2)T_2^4} \quad .. \quad .. \quad .. \quad .. \quad .. \quad (11)$$

We shall assume here that T_1 is 900° K. (627° C.) and T_2 is 450° K. (177° C.). If we let $z = \frac{2}{3}$, the over-all efficiency of the heat engine $= \frac{1}{3}$ and, if P is 1,500,000 watts, we find, for the assumed 10-ton ship,

$$A_r = 1{\cdot}9.10^7 \text{ cm.}^2 \quad .. \quad .. \quad .. \quad .. \quad .. \quad (12)$$

This would yield a cooling area roughly 30 metres square, radiating on both sides.

4. Electrical Acceleration of the Propellant

We compute the electrical current required to accelerate a beam of ions for rocket propulsion. The current is related to the power P, in watts, and the potential V in volts by the relationship

$$P = iV \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (13)$$

The potential V across which the ions are accelerated is determined from the energy equation

$$\frac{eV}{300} = \frac{1}{2}mv_a^2 \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (14)$$

where e is the charge on each ion, equal to $4{\cdot}8.10^{-10}$ electrostatic units if each ion is singly charged, and m is the mass per ion. For nitrogen atoms, m is $2{\cdot}32.10^{-23}$ grams, and if we again let v_a equal 10^7 cm./sec., we find

$$V = 730 \text{ volts} \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (15)$$

Thus, for a power of 1,500,000 watts, we have

$$i = 2{,}000 \text{ amperes} \quad .. \quad .. \quad .. \quad .. \quad .. \quad (16)$$

With so large a current, space-charge limitations must be considered. If the potential drop V occurs across a gap x, the maximum current density, j amperes per cm.^{2}, is given by

$$j = \frac{2^{\frac{1}{2}}}{9\pi x^2.3.10^9}\left(\frac{e}{m}\right)^{\frac{1}{2}}\left(\frac{V}{300}\right)^{3/2} \quad .. \quad .. \quad .. \quad .. \quad (17)$$

The area A_i of the ion source is evidently given by

$$A_i = \frac{i}{j} \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (18)$$

If we substitute for i from equation (13), for j from equation (17) and for V from equation (14), we find

$$A_i = \frac{36\pi x^2 e^2 P 10^7}{m^2 v_a^5} \quad .. \quad .. \quad .. \quad .. \quad .. \quad (19)$$

For a power of $1{\cdot}5.10^6$ watts, a velocity v_a of 10^7 cm./sec., an accelerating gap of 0·1 cm., and for nitrogen ions as the propellant, we find

$$A_i = 7{\cdot}2.10^4 \text{ cm.}^2 \quad .. \quad .. \quad .. \quad .. \quad .. \quad (20)$$

This area of about 7 square metres required for the ion source is much smaller than the area required for radiative cooling.

DESCENT FROM SATELLITE ORBITS USING AERODYNAMIC BRAKING

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SUMMARY

This paper describes the application of some of the author's theoretical work (mostly as yet unpublished) to the problem of the descent of an aircraft from a circular orbit; when the aircraft reaches the denser regions of the atmosphere, it is assumed that the remainder of the descent is a shallow dive during which the aircraft, supported by the lift of its wings, gradually slows down. The theoretical work is intended to provide an estimate of the temperature reached by the aircraft in this glide.

The calculation of the rate of heat transfer, caused by air friction, to a body moving at very high speeds presents a problem which cannot, in general, be accurately solved. However, an approximate general solution has been obtained which compares fairly well with an accurate particular solution. In fact, it appears that the heat transfer may be satisfactorily assessed in flight at Mach Numbers of 10 or more if the Reynolds Number is between about 10^5 and 10^6. This, as it transpires, is the condition in which we are most interested. The effects of the "slipping" of the air at the surface—a phenomenon caused by the molecular structure of the air—have also been examined, and lead to an estimate of the maximum rate of heat transfer to the surface. A limit to the skin temperature is also imposed by the conduction of heat along the surface; this has been calculated as well.

It is then shown that the wing surface temperature will be least if a thin, double-wedge wing-section is used, with a position of the maximum thickness well aft, and with both its inner and outer surfaces acting as good radiators of heat. The temperature will be highest near the leading-edge of the wing undersurface, and its value there depends on the wing-loading—varying roughly as the fourth root of the loading. A maximum temperature of 1300° C. is reached during the descent, assuming a wing-loading of 30 Kg.s./m., occurring when the speed has dropped to 4·6 Km./sec. The *mean* temperature of the wing surface would be much lower—about 500° C.

Although existing data are inadequate to deal with the question, there is a possibility that, as an alternative to a gradual descent, a more rapid one involving a dive, in which dive-brakes are used to provide a retardation of 4 or 5 g. might be a better means of descent. Alternatively, as slow a descent as possible seems best, in general, because any unnecessary manoeuvre such as a dive, requires extra weight of structure in the wing to provide adequate stiffness at the higher air speeds. To reduce the structure weight it is necessary, in fact, to limit the indicated air speed during the glide; if an indicated speed of 60 m./sec. is not exceeded, it should be possible, for example, to accommodate a payload of 5 tonnes within an aircraft of 20 tonnes all-up weight, some two-thirds of this weight being due to the structure of the reinforced steel wing. This figure is derived assuming an all-wing design using a delta planform of high sweepback. The transport of a much heavier payload than this would be impossible, unless a more suitable material than steel could be found economically to provide strength at high temperatures. Smaller payloads could be carried without such a severe penalty in structure weight.

Having in mind the low wing-loading required, an all-wing design is a natural choice. Apart from a lack of depth, there would appear to be no reason why the payload could not be housed within the wing. Moreover, given suitable insulation from radiation, there would appear to be no need to cool the crew's accommodation, which, however, would need to be as far away from the wing leading-edge as possible.

Assuming that the aircraft is initially circling the Earth at a height of some 1,200 Km., a retardation—by rocket—of about 400 m./sec. would be necessary to change the orbit into an ellipse and bring it to a height of about 80 Km., where the wings could be brought into use. The complete descent would take over three hours, during which time the aircraft could at least twice encompass the earth.

A paper read to the Second International Congress on Astronautics in London, September 6, 1951.

1. Introduction

The design of a vehicle which can return to Earth from a circular orbit will present, inevitably, a difficult and involved problem. It is impossible in a discussion such as this to do more than suggest a solution of one or two particular difficulties. Of all these, frictional heating seems to involve the greatest likelihood of hazard, and is at the moment one of the most important unknown factors. It is, I think, often accepted that such a vehicle would indeed be unable to enter the bulk of the earth's atmosphere without first being retarded, to a relatively low speed, by forward-firing rockets—otherwise (it is contended) it would be burnt up by the intense heat generated by air friction.

Certainly the vehicle will become hot if it enters the denser region of the atmosphere at high speed, and the question is only whether it will become *too* hot. The argument we shall advance here is that—even without using retarding rockets—the temperature involved need not be impossibly high. If this is so, and the complication of forward-firing rockets may be avoided—implying as it does a tremendous penalty in weight—at least one very big problem associated with the descent from a satellite orbit will have been disposed of.

Unfortunately, the problem of heat transfer at such high speeds as are involved in the descent has not been a subject which has received much attention. There are no experimental data, and there is little theory, to help us. Nor is there any published information concerning the properties of existing high-tensile steels, for example, at very high temperatures (above some 1100° K) that we may judge what temperatures are reasonable, even if these could be predicted with much assurance.

At first sight, then, the problem posed would not appear capable of solution at the present time. But as a contribution towards an ultimate solution, and the basis of this discussion, this paper outlines the results of some theoretical studies of various aspects of the heat transfer problem at high speeds. It has not been found possible to publish this work *in extenso* yet, but a summary is given here so that its limited scope is appreciated and so that the results can be directly applied to the estimation of temperature. As a theory unverified by experiment, it must be suspect, but at least it is one stage more reliable than an arbitrary extrapolation of irrelevant data.

The lack of metallurgical data need not trouble us very much. In any event, enough information exists to make a sensible extrapolation for the range of temperature as yet unexplored: even if the results are optimistic by present-day standards, there is no reason why the rapid improvements in this branch of technology should not remedy this in the near future.

We shall, then, consider only the problem of surface heating—touching upon other problems only where they affect this one—and, further, we shall limit the discussion to those deductions which can be drawn from the theoretical work. The vehicle itself we assume to be piloted; if it is to be retarded slowly by the atmosphere alone it must be glided down to earth, in a very shallow dive, sustained by the lifting force on its wings; these wings, too, must be capable of landing it like any other aircraft. Without wings, it has

been shown[1] that the descent would be precipitate, and disastrous to any crew.

A complete design study of the craft cannot be attempted, and assumptions about the design will be made, where these do not directly affect the estimation of temperature. The one important factor of design will be shown to be the choice of wing-loading: the temperature may be lowered by increasing the wing area (and so reducing the loading), but this involves a weight penalty which it will be the main purpose of this analysis to assess.

2. A Summary of the Theoretical Work

2.1 *Heat Transfer at High Speeds*

The only part of this work which has been published is contained in Ref. 2. This deals with the heat transfer to a surface (over which the air pressure is constant) moving at a high speed through the atmosphere, at a height where the boundary layer flow is laminar and there is no slipping of the air at the surface. Provided that the Mach Number of flight is sufficiently high, the rate of heat transfer to the surface is shown to be virtually insensitive to variations in surface temperature—unless this is unrealistically high. At a position distance x (metres) from the leading-edge of the surface, the input of heat from the boundary layer per unit area is given by

$$66\ U^3 \sqrt{\frac{p}{x}} \qquad \text{Kw./sq.m.}$$

Where p is the air pressure on the surface (in atmospheres)—assumed invariant with x,—and U is the flight speed in Km./sec. Under the same conditions the skin-friction intensity is shown to be

$$12\ U \sqrt{\frac{p}{x}} \qquad \text{Kg./sq.m.}$$

Although the surface pressure is assumed uniform, the results are valid if it differs from that of the undisturbed air (p_a); however, because it is assumed that the air just outside the boundary layer is flowing at a high Mach Number it follows that the compression ratio (p/p_a) must not be too large. The theory is, in fact, applicable to "slender bodies" only—in practice, an angle of attack of 10° would be a reasonable upper limit, beyond which the theory is inapplicable.

This solution was obtained by integration of the momentum and energy equations to the flow across the boundary layer, using approximate expressions for the variation in temperature and velocity (based on the known boundary conditions). Variation of the air specific heat, molecular weight, etc., with temperature was taken into account in formulating the boundary conditions.

2.2 *An Exact Solution of the Problem*

The method explained above—although approximate—gives very good results when applied to incompressible flow problems; but its accuracy if applied to the compressible boundary layer—where the variation of temperature is so marked—must be in doubt. Unfortunately, it is not possible in general

to obtain an exact solution to the problem, if varying specific heat and molecular weight are to be taken into account, so no direct comparison of the method is available to confirm its accuracy. However, if it is assumed that the Prandtl Number of the air is unity, and if dissociation effects are neglected, a series-solution of the fundamental differential equations can reasonably be attempted; from this it follows that, for flight at very high speeds, the rate of heat transfer and skin friction intensity vary in the manner described in the previous paragraph, but the estimated values are some 30 per cent. less. Although the approach is rigorous, the underlying physical assumptions are less real than those made before, so it is not possible to suggest that the method under discussion is likely to give better results; but the fact that the results of Ref. 2 give a larger answer is some reason for believing that they are not unduly optimistic.

2.3 *Range of Applicability of the Results*

Having in mind then the kind of accuracy which we may expect from the results of Ref. 2, it is possible to make some realistic estimate of the heights where conditions are such as to justify the assumptions made in deriving these results. Such an assessment suggests that—providing some correction is made for the effects of surface slip—the results are valid for flight at a Mach Number of 10 or more and for Reynolds Numbers between 100 thousand and 100 million. These figures are of course very approximate. The upper limit in Reynolds Number indicates flight at a height where the air density relative to sea-level is—in a typical case—about 0·01 (i.e. 20 miles up) below which altitude turbulence in the boundary layer would occur and invalidate the results. However, it is most unlikely that flight at such high speeds as are envisaged would take place at lower altitudes than this—merely because the indicated air speed would be unreasonably high. The lower limit in Reynolds Number corresponds—again, typically—to flight at a height of some 50 miles where the air density is 10^{-5} of that at sea-level. Above this height, various manifestations of finite molecular free path become evident—quite apart from surface slip—but frictional heating is still the most important single source of heat transfer even at such altitudes.

2.4 *The Effects of Surface Slip*

The effects of surface slip upon the structure of the boundary layer may be dealt with quite simply on the basis of the Kinetic Theory of Gases. The treatment is still further simplified if the correction to be applied to the results obtained by assuming the air homogeneous is taken to be relatively small. It may then be shown that—correct to the first order of approximation—the skin friction intensity is unchanged, whereas the heat transferred is *reduced* by a fraction

$$3{\cdot}4\,\frac{Mc_f}{\alpha}\sqrt{\frac{T_o}{T_b}}$$

where M is the local Mach Number outside the boundary layer, c_f the local skin friction coefficient, and α is the so-called "accommodation coefficient"—being that fraction of the impinging molecules which adhere to the surface

(instead of being specularly reflected). The temperatures T_o and T_b are those at the surface, and the outside of the boundary layer, respectively.

The reduction becomes relatively larger near the leading edge of the surface (since c_f varies as $1/\sqrt{x}$), where the uncorrected rate of heat transfer becomes infinite. There is, as a result, a finite maximum rate of heat transfer; but it cannot be found from the above expression, since this is valid if and only if, it is a *small* correction term. However, the accurate determination shows that the heat transfer does not exceed

$$4{\cdot}2\ pU \qquad \text{Kw./sq.cm.}$$

where, as before, p is in atmospheres and U in Km./sec. This maximum is found by considering the maximum amount of heat which individual molecules can impart—which must be finite.

2.5 *The Effects of Skin Conductivity*

Although surface slip sets a limit upon the rate of heat transfer, so also does the conductivity of the material of the exposed skin. The conductivity tends to redistribute the heat more evenly, so reducing the temperature where the heat input is highest. To estimate its effect upon the temperature of the skin near the nose, we need to make several assumptions: thus, if we are dealing with a thin skin exposed on the inner-surface to a non-conducting medium and the rate of heat transfer to the outer surface is given by an expression

$$\frac{1}{2}Q\sqrt{\frac{L}{x}}$$

then the maximum surface temperature reached is given by

$$T_{max} = 1{\cdot}05\ T_m\left(\frac{L^2Q}{T_m k d}\right)^{1/13} \qquad \text{where } T_m = \frac{Q}{2\sigma\,(\epsilon_o + \epsilon'_1)}$$

Here L is the length of the surface, k the skin conductivity, d the skin thickness, σ is Stefan's constant, ϵ_o the emissivity of the outer surface, and $\epsilon'_1 T^4_{max}$ is the total rate at which heat is lost locally from the inner-surface. It is assumed that the skin is sufficiently thin that

$$\frac{T_m k d}{L^2 Q} \ll 1$$

If this is so, then conductivity is only important in affecting the surface temperature very near to the nose—where the temperature is within about 20 per cent. of the maximum determined above.

2.6 *Radiation from the Boundary Layer*

Radiation from the air may generally be ignored. A careful study has indicated that the heat radiated from the boundary layer is certainly less than 0·1 per cent. of that conducted into the surface from the air, for all speeds of flight less than the circling velocity, and at distances up to several hundred metres from the nose of the surface. The height of flight is unimportant except in so far as it influences the water-vapour or ozone content of the air,

because both radiation and conduction in general decrease as the square root of the air pressure.

2.7 *The Scope and Accuracy of the Work*

These half-dozen papers deal with some of the problems relevant to the question posed in this paper. Yet they are evidently limited in both scope and accuracy. One obviously important problem not yet touched upon concerns the state of the boundary layer subjected to a varying surface pressure; only a few particular examples of no great interest can be worked by by methods of Ref. 2. However, these omissions will not trouble us if it is possible to answer all the relevant questions within the confines of the applications of the work already mentioned. Any additional information may possibly suggest methods by which the practical difficulties we are discussing could be more easily overcome: but it is difficult to foresee how any such work might suggest that these difficulties could *not* be overcome by the methods we suggest.

This is quite apart from the general question of accuracy of the data. To put this point in its true perspective, it should be noted that we are most interested in skin temperature, which is related to the estimated rate of heat transfer in such a way that even an error of 40 per cent. in this estimate would imply no more than an inaccuracy of about 10 per cent. in temperature prediction. Fortunately, the result which we shall use most—the maximum rate of heat transfer as determined by surface slip—is the one in which greatest reliance may be placed: it seems most unlikely that it can be in error by more than a few per cent. However, it is a safe and valid conclusion that, although the results all give at least a rough idea of the true quantitative answer, they are of more value in demonstrating qualitative variations.

3. The Pressure on the Wing Surface

The theoretical results detailed above are applicable only to a wing surface over which the pressure is constant, and if the heat transfer is to be as small as possible, this pressure must be as low as possible. A wing of given area which has to develop a certain lift does so, then, with least transfer of heat if the section shape and angle of attack are such that the wing under-surface is subjected to a certain (uniform) pressure whereas that on the upper surface is zero.

There are, however, practical reasons why it is not possible to design exactly to these conditions. The pressure on the upper surface may be reduced by making the wing thin and by increasing the altitude of flight—so decreasing the value of the free-stream pressure, and increasing the necessary angle of attack (and so also the expansion ratio over the upper surface). It is not thought practicable, however, to design a wing with a thickness less than 5 per cent. of the chord; and flight at an altitude greater than that where an angle of attack of 10° is required would not be amenable to study by the methods of para. 2 (see para. 2.1).

Also, since it is necessary to avoid assymmetrical loads during the ascent of the aircraft from the Earth, a cambered wing section—which would be required

to provide a uniform pressure on the wing's (plane) under-surface—is impracticable; the most suitable symmetrical section would resemble a double-wedge with the maximum thickness as far aft as compatible with a reasonably small trailing-edge angle. The thinner the wing, the further back the maximum thickness position, and consequently the greater will be the effective lifting surface of the wing—since the bulk of the lift is carried on the forward part of the under-surface.

This may best be shown by an example: taking 12° as a reasonable trailing-edge angle, a 5% double-wedge section could be designed with a maximum thickness at 0·75 chord aft of the leading-edge. At an angle of attack of 8° and at a Mach Number of 15, say, the pressure on the under-surface will be 11 atm. on the forward part, and 2 atm. on the rear, whereas that on the upper surface will be about 0·1 atm. forward and 0·001 atm. aft of the maximum thickness. Most of the lift is being carried on the forward part of the under-surface where the pressure is only about 25 per cent. higher than the overall wing loading.

It is not contended that this wing section is the most suitable that could be designed. It merely appears as the best of those which can be dealt with on the basis of the available theory.

In trimmed level flight, the proportion of the lift carried on the rear under-surface might be altered if this part of the wing is used as a trimming surface. The untrimmed centre-of-pressure of such a section as that just described, if applied to a delta wing platform, would be well forward in the high-speed condition described, and little trim would presumably be needed.

4. Radiation from the Wing Surfaces

The emission of radiation from a heated surface may be anything between about 4 to 97 per cent. of that from a true black body. The lowest emissivities are impossible to attain from metals except at very low temperature: emissivity increases with temperature and is at least about 15 per cent. at temperatures around 1,000° K. Its actual value will of course depend upon the quality of the metal surface.

If the metal skin of the wing is receiving heat from the air, in order not to reach too high a temperature, it must radiate away as much of this as possible. Radiation from the outer surface will merely be "lost" but radiation from the inner surface will heat the opposite skin of the wing and other internal structure.

Near the leading-edge of the wing under-surface, where the heat transfer is highest, the temperature will probably be so high that little can be done to prevent heat from being radiated outwards as from a black body, from both inner and outer surfaces. However, we may choose whether or not we allow this heat to be reflected from the upper surface, which is only receiving a heat input from the air equal (say) to a fraction a of that received by the under wing surface. The balance of the heat escaping to the inside from the wing under-surface, after subtracting the heat absorbed from that

radiated, may be shown to be equal to $\epsilon'_1 \sigma T_1^4$, where, near the nose of the wing

$$\epsilon'_1 = \left(1 - a\frac{\epsilon_0}{\epsilon_3}\right) \Big/ \left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} + \frac{1+a}{\epsilon_3} - 1\right)$$

and the temperature of the under-surface is T_2 where

$$\left(\frac{T_2}{T_1}\right)^4 = \frac{(1+a)\,\epsilon_1\,\epsilon_2 + a\epsilon_0\,(\epsilon_1 + \epsilon_2 - \epsilon_1\,\epsilon_2)}{(1+a)\,\epsilon_1\,\epsilon_2 + \epsilon_3\,(\epsilon_1 + \epsilon_2 - \epsilon_1\,\epsilon_2)}$$

Here, T_1 is the temperature of the under-surface and ϵ_0, ϵ_1, ϵ_2 and ϵ_3 are respectively the emissivity of the outer and inner surface of the wing underside, and the inner and outer surface of the upper wing skin.

It will be seen that the rate of loss of heat due to radiation from the under-surface is greatest if both surfaces of the upper side of the wing are good radiators. Assuming—using the results of para. 3—that $a = 0{\cdot}1$, it then follows that $\epsilon'_1 = 0{\cdot}41$, and $T_2 = 0{\cdot}87T_1$. The temperature of the upper surface may, however, be reduced by making its inner surface a good reflector: if we assume, in fact, that $\epsilon_3 = 0{\cdot}15$, then $\epsilon'_1 = 0{\cdot}12$, but $T_2 = 0{\cdot}70T_1$. By making the top inner surface a good reflector, we therefore reduce the temperature of the upper surface by some 15 per cent. at the expense of a six per cent. increase in the temperature of the lower surface. Whether this is, or is not, the right thing to do is difficult to say: we shall return to this point later.

5. Maximum Wing Surface Temperature

In para. 2, two limits upon the temperature of the surface were suggested: due to surface conductivity and the finite molecular free path. This latter consideration (para. 2.4) suggests a limit to the rate of heat transfer which varies as pU. Now, it can be shown, from the data of para. 3, that on the wing forward under-surface, in level flight,

$$p = 1{\cdot}25\,l\left(1 - \frac{U^2}{gR}\right)$$

where l is the wing-loading, and $\sqrt{gR}$ the circling velocity near the Earth's surface. Hence, the maximum rate of heat transfer is greatest at a speed such that

$$U^2 = \frac{1}{3}\,gR$$

i.e. at 4·6 Km./sec. The maximum rate of heat transfer is then

$$16l \quad \text{Kw./sq.m.}$$

where l is in Kg./sq.m. Equating this with the rate of heat loss by radiation, where—in the notation of para. 4—we take $\epsilon_0 = 0{\cdot}97$ and $\epsilon'_1 = 0{\cdot}41$ (i.e. assuming the surfaces to be all good emitters), we find that

$$T_{max} = 670\,l^{1/4} \ ^\circ K$$

is the maximum temperature reached by the under-surface during a descent from a circling orbit, as determined by considerations of surface slip.

On the other hand, that determined by skin conductivity may be shown—using the results of paras. 2.1 and 2.5—to be dependent on a rate of heat transfer which varies as $(pU^4)^{2/13}$: evidently this is greatest when $U^2 = \frac{2}{3}gR$ (at 6·5 Km./sec.), and at this speed

$$T_{max} = 1050\ [l^2/kd]^{1/13}\ ^\circ K$$

where k is the skin conductivity (m cal./cm./sec./deg. C) and d is the skin thickness (in mm.).

Assuming the skin material to be steel (and in the above units, $k = 0{\cdot}15$) then, for $l = 30$ Kg./sq.m., say (i.e. 6 lb./sq. ft.), we may calculate that the maximum temperature determined by surface slip is 1300° C., whereas that imposed by skin conductivity is 1800° C. for a skin 1 mm. thick. It would need a skin about 3 cm. thick to put a lower ceiling on the temperature than that imposed by surface slip: such a thick skin is not wanted for any other reason, so that the upper limit to the temperature will not generally be set by considerations of conductivity.

The variation of T_{max} with speed is given by

$$\left\{\left(\frac{U^2}{gR}\right)^{1/2}\ \left(1 - \frac{U^2}{gR}\right)\right\}^{1/4}$$

if determined by considerations of surface slip, or by

$$\left\{\left(\frac{U^2}{gR}\right)^{2}\ \left(1 - \frac{U^2}{gR}\right)\right\}^{2/13}$$

if conductivity sets a lower limit. Thus it appears that conductivity will determine the maximum skin temperature only at low speeds: in the comparison quoted above, for example, at speeds below two per cent. of the circling speed. If the skin is much thicker than the 1 mm. considered, it is possible that with the limit imposed by conductivity at low speeds, and by surface slip at higher speeds, the greatest temperature reached is less than the maximum imposed by either: but this is not generally so.

6. Effect of Diving Flight

The temperatures so far considered have been those reached in steady, level flight. Strictly speaking the flight is neither level nor steady. In fact, by diving the aircraft whilst it is decelerating past the critical speed range where the heat transfer is greatest, it should be possible to reduce the highest temperature reached. For, by diving, the load on the wings is relieved, and also the pressure on the wing under-surface.

An examination has been made of the trajectory resulting from a dive, in which the lift programme is so arranged to maintain a constant maximum temperature on the under-surface; then—assuming that the aircraft is retarded by dive brakes—if the drag retardation at the bottom of the dive (where it is greatest) is as much as 5 g, the speed at the beginning of the dive is only a little

beyond the circling speed. Thus the wing surface maximum temperature corresponds to that in level flight at this high speed, and is consequently reduced from that in a descent in nearly level flight. However, this takes no account of the heat transfer to the surfaces producing the high drag, which—being subjected to a high pressure—will become much hotter than the wing surface. Unfortunately this effect cannot be calculated by the methods outlined in this paper; plainly, the possibility of a more rapid descent exists and may even prove more satisfactory than the lengthier flight path suggested here. Apart, of course, from the effects of excessive "g" even a vertical descent may be a practical possibility, as suggested in a previous paper.[1]

These effects must be examined again when theoretical information is available to assess the heating of the dive brakes. At least it is evident that without dive-brakes where the drag is at most about 0·1 g, a similar dive can start at a speed only some 10 per cent. above that at which the heat transfer in level flight is a maximum. It follows that the heat transfer in the dive is two or three per cent. less, and the maximum temperature only $\frac{1}{2}$ per cent. less, than the maximum in level flight. In general, in terms of this retardation (ng) at the bottom of the dive we can show that, very roughly, the temperature is reduced by a fraction 0·06 n. We shall have more to say later, about the advisability of diving flight.

The question of whether the skin actually reaches the equilibrium condition—i.e. whether it has time to heat up to the equilibrium temperature—is easier to answer. The maximum rate of heat transfer will be of the order of 300 Kw./sq.m. or more; this is being supplied to a skin of possibly not more than $\frac{1}{2}$ cm. thick locally. To reach 99 per cent. of the equilibrium temperature would require this rate of heating for three minutes, and after each further 45 seconds the temperatures will be 10 times closer to the equilibrium condition. But in one minute the aircraft will have decelerated by some 100 m./sec., so that some half-hour of gliding flight is required before the speed at which the heat transfer is a maximum will be reached. After such a time, during which the skin is being continually heated, its temperature will evidently have reached a value indistinguishable from the equilibrium condition.

7. Selection of Wing Loading

It was shown, in para. 5, that the highest temperature reached by the wing surface is determined by considerations of the effect of finite molecular free path upon the boundary layer structure, where it is very thin—near the wing leading edge. This highest temperature varies with the applied air pressure on the wing, and hence depends upon the wing loading; the variation was given in para. 5 as

$$T_{max} = 670\, l^{1/4}$$

Assuming for the moment that steel is to be used, a wing loading of more than 40 Kg./sq.m. could not be used because this implies that $T_{max} = 1400°$ C. which is the melting point of steel. On the other hand a steel wing is unlikely to weigh *itself* much less than 10 Kg./sq.m. and this loading implies a maximum

temperature of 900° C. We might then expect the wing temperature to be between 1,000 and 1,300° C., and the loading between 15 and 30 Kg./sq.m. Roughly, the wing structure weight will vary inversely with the loading, unless there is need for special reinforcement of the structure to provide strength at high temperatures; presumably, some stage will be reached where further increase in wing loading (and skin temperature) will no longer reduce structure weight, because the increase in weight of the special reinforcement necessary outweighs the saving in structure weight due to reduced wing loading.

Bearing in mind that—apart from the determination of its melting point—no information has so far been published concerning the properties of steels above 850° C., little is to be gained by attempting to predict this optimum wing loading.

All that can be said is that a simple extrapolation of existing data suggests that, at 1,300° C., the tensile strength of some special steels might be still one or two per cent. of that at ordinary temperatures, in which event we may assess the weight of reinforcement needed to the wing to be at the most about 60 Kg. per metre of wing span. This is a more important fraction of the weight of a small aircraft than a big one: this is because the extent of the hottest regions of the surface does not depend on the area, but only the span, of the aircraft's wing. Thus, the reinforcement would be typically, about 5 per cent. of the weight of a 50-tonne aircraft, but 20 per cent. of an aircraft weighing, say 5 tonnes. Nevertheless, the extra weight is sufficiently small to suggest that the true optimum maximum skin temperature might lie even closer to the melting point of steel.

It will be recalled that in para. 4 the question was posed whether the reduction in the temperature of the bulk of the wing structure—by making all inner surfaces, except that of the under-surface, good reflectors of heat—would be beneficial. The heat radiated away from the under-surface is then reduced by about 25 per cent. and so, if the maximum temperature of the wing surface is not to rise higher than 1,300° C., it follows that the pressure on the surface—or, in other words, wing loading—must also be reduced by 25 per cent.—from 30 to 23 Kg./sq.m. But this implies at least an increase of 25 per cent. in wing structure weight—or certainly more than the weight of the reinforcement necessary on a big aircraft, in any case. Thus no advantage can be claimed for this insulation as a method of reducing structure weight.

We may therefore suggest that, even with existing high-tensile steels, a maximum surface temperature of 1,300° C. might be reached, implying a wing loading of 30 Kg./sq.m., without much special reinforcement to the structure being necessary. The use of other materials such as the ceramics with higher melting-points, would certainly allow an increase in wing-loading, but whether it would also permit a decrease in structure weight is difficult to say at the present time, when the method of construction then necessary is so obscure.

8. An Estimate of Structure Weight

It is essential to attempt some estimate of the weight penalty involved in the use of a low wing-loading and to make some guess at the right kind of wing design. Yet the doubt that must be attached to any such estimate is only too

obvious, in view of the unusual flight conditions; no particular merit can be claimed for the estimates we give now, except that they are founded on present aircraft experience.

If we need a low wing loading, it will be natural to rely on an all-wing design, since there should be enough room inside the large wing to house the payload—an assumption to which we shall return later. This implies a swept wing, and because of its favourable stability characteristics, we shall choose a delta planform. This is, admittedly, an expedient choice rather than a necessary one.

Assuming that the payload inside the wing provides an effective relief load to compensate for the bending load on the wing, the wing weight will be least for small thickness/chord ratio and aspect ratio. With the former at least equal to five per cent., an aspect ratio a little above unity would appear best—i.e. a delta wing with an apex angle of about 40°. More than anything else, the weight will be critically dependent on the maximum indicated airspeed at which the aircraft is likely to travel; an increase in this will imply that the wing has to be strong enough to cater for the possibility of increased loads due to flutter. In fact, a large all-wing aircraft needs a weight of material in the wing to provide stiffness which varies (roughly) as the square root of the indicated speed.

This fact is relevant to the question posed in para. 6 relating to the advisability—or otherwise—of diving to reduce the heat transfer. If the terminal retardation at the bottom of the dive is ng, then from the data of para. 6, it follows that the maximum skin temperature is reduced by a (small) fraction $0{\cdot}06\,n.$: so that if it is preferably to be kept at a constant value, we can afford to increase the wing loading by a fraction $0{\cdot}24\,n.$—thereby reducing the wing structure weight by a similar fraction at least. Roughly the retardation is about

$$n = \frac{0.6}{l}\left(\frac{V_D}{100}\right)^2$$

where V_D is the maximum indicated speed in the dive (in m/sec.). Hence the wing weight is reduced by a fraction proportional to V_D^2 as a result of the permissible increase in loading, but is increased by a factor proportional to $V_D^{1/2}$ due to the need for increased stiffness. Clearly for smaller values of the indicated speed the latter effect far outweighs the former, and it is only for values of V_D in excess of about 1 Km./sec. that the tables are turned: such a speed implies a final retardation of at least 2g at a height so low that the boundary layer is most likely no longer laminar, but turbulent—at an altitude of 10 miles, in fact. A dive to an even lower altitude would be necessary to obtain the full advantage of the permissible higher wing loading, but the problem cannot be dealt with by the methods of this discussion. It is, clearly, an example of the use of a dive involving a retardation of up to 4 or 5 g, say, as a possible alternative to the less rapid descent—an alternative which we remarked upon in para. 6.

Certainly a shallow dive is disadvantageous as it increases the weight

required to make the wing stiff. By adhering to strict flight plan during descent, it should not be necessary to exceed an indicated speed given by

$$V_D = 12\, l^{1/2} \text{ m./sec.}$$

This is sufficiently high to allow an approach during landing at a reasonably low angle of attack: on the other hand, it cannot be reduced without necessitating a higher angle of attack at high altitudes than we have previously considered—that is, above some 10° or so.

We now have sufficient information on which to base a reasonable estimate of the complete weight of structure necessary. It becomes relatively larger as the all-up weight is increased—a manifestation of the square-cube law—and there is an all-up weight such that any further increase in weight would necessitate an even greater increase in structure weight; an aircraft of this size will carry the maximum possible payload. In the present instance, it appears that—making due allowance for all items of structure—a payload of at most seven tonnes could be carried, and this by a glider of 45 tonnes.

This figure, of course, refers to an aircraft of the particular type envisaged—of 30 Kg./sq. m. wing loading. The maximum permissible payload is, in fact, increased if the wing loading is increased—it varies as l^2, approximately; this is because wings of higher loading are smaller in area and can be designed to be relatively lighter. But we have seen that (in para. 5) an increase in loading implies an increase in surface temperature so that we have the relation:

$$\text{max. payload} \propto (\text{max. temperature})^8$$

Other things being equal, the use of a material which would permit the use of a maximum temperature of 2,000° C. (instead of 1,300° C.) would also allow an increase in wing loading of from 30 to 140 Kg./sq.m., and a permissible increase of maximum payload to 130 tonnes (in a glider of some 850 tonnes all-up weight). Whether or not such a hypothetical material could provide the same strength as a steel wing for the same weight is open to doubt; some ceramics seem to offer promise and since the high temperature regions are very localised, only a small area of ceramic skin would be needed. Bonding with the metal structure is the obvious snag.

The variation in the payload weight as a function of all-up weight is shown in Fig. 1. A small reduction in payload, below the maximum, results in a considerably saving in weight: a payload of five tonnes, for instance, can be accommodated with an aircraft of some 20 tonnes all-up weight. This tendency is borne out by the economies to be effected by still further reductions, but is ultimately offset by the relatively larger weight of reinforcement necessary for the wings of the smaller aircraft: thus, the least percentage structure weight is some 70 per cent. for an aircraft carrying two tonnes of payload, as compared with the 85 per cent. of the 50 tonne aircraft.

It will be, then, with payloads of round about five tonnes that the method of design and descent outlined in this discussion will be most suitable. We can expect that the transport of a heavier payload would present a difficult problem —saving help from metallurgical research developments. Even the loads we

have in mind would necessitate the design of an aircraft with at least 60 to 70 per cent. of its weight devoted to wing structure, which is a considerable penalty to judge by the standards of conventional aircraft. The design of smaller aircraft should present less of a problem than we have suggested, for a lot of the assumptions we have made are then inappropriate.

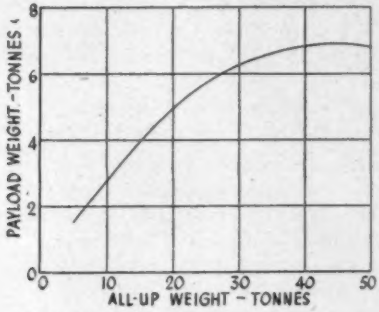

FIG. 1. Payload as a function of aircraft size: (wing-loading 30 Kg./Sq.m. maximum skin temperature 1300° C.)

9. Rocket Braking

So big is this structure weight necessary, that it might well be objected that the retardation might more easily be obtained by using forward-firing rockets; the weight penalty is, in effect, that of a single-stage rocket. However, it should be borne in mind that if such a descent is to be accomplished satisfactorily most of the kinetic energy of the missile will have to be destroyed by this means, as the highest temperatures are reached at quite low speeds; and even then presumably, some sort of wing would be necessary to guide the missile when it reaches the atmosphere and lands in a suitable locality. Thus a conservative estimate would suggest that at least 20 or 30 per cent. of the weight of the missile would be devoted to structure (including wings) in any case and with 10 per cent. devoted to the rocket motors, say, a mass ratio of less than two would be obtained—unless the payload were to be significantly smaller than suggested in the previous discussion of the winged descent. For rocket-braking to be more economical then, a rocket missile with a possible mass ratio of less than two must effect a deceleration of something like 7 Km./sec.; this is asking for an exhaust velocity of more than 10 Km./sec. It is tempting to suppose that by the time we have propellants capable of such performance, high-temperature metallurgy may have suggested some material which could more easily and efficiently withstand the rigours of the winged descent.

10. Payload Accommodation

Without knowing the kind of equipment to be carried, it is difficult to suggest whether there will be room in the wing for it, or whether a fuselage of

some sort would be necessary. A modern jet-propelled fighter aircraft, in which everything is packed fairly tightly to occupy the least room, has an overall density at take-off of about 300 Kg./cu.m. Its crew, flying and power services and "payload," are accommodated with a density of something like 40 Kg./cu. m. Knowing these figures, it is possible to appreciate others in their true perspective. The aircraft of 20 tonnes weight, suggested in para. 8, encloses a volume of 500 cu. m., so that it follows that the payload is accommodated with a density of 10 Kg./cu. m.: this does not suggest an impossible state of overcrowding. The only possible snag lies in the shape in which the load must be stowed—the inside of the wing being very long, not very wide, and for the most part certainly lacking in height. Thus, for instance, the greatest thickness of the 20 tonne aircraft is only just over two metres.

Assuming the payload could be satisfactorily stowed there is still the question of how it would be affected by the temperature of the interior. Most of the heat would come from radiation, since it is not difficult to support the load so as to do away with most of the sources of conduction. Even radiation can be appreciably cut down. It follows from para. 4, that the transfer of heat to the inside of the wing is least if both surfaces of the structure enclosing the payload are made good reflectors as well as the inner surface of the wing skin nearby (i.e. ϵ_1, ϵ_2 and ϵ_3 are all as small as possible). Whilst such measures as these could not be taken near the leading-edge of the wing, where the heat transfer is highest—since they would react, as we have seen, upon the maximum temperature of the wing surface—such insulation would be possible near the trailing-edge. Also, since the heat transfer varies inversely as the square root of the distance from the nose, the coolest place will be near the trailing edge at the root; here the heat input to the under-surface (of the 20 tonne rocket) would at most be about 15 Kw./sq.m. as calculated from para. 2.1, (corresponding to a skin temperature of 400° C.). Suitable insulation might well reduce the amount of this heat actually escaping into the interior of an enclosed cabin within the wing by a factor of 1/60; but a heat input of $\frac{1}{4}$ Kw./sq.m. is much less than that due, for instance, to solar radiation intensity—which has the value of about $1\frac{1}{2}$ Kw./sq.m. at the earth's distance. Thus, there seems no need to make provision for special refrigeration of the contents as those items of payload which must be kept cool can easily be insulated.

11. Descent from the Circling Orbit

The aircraft—at first in a circular orbit at some considerable distance from the Earth's surface—must reach the glide path within the atmosphere by some form of deceleration, which subtracts just enough energy from the aircraft in the circular orbit to turn it into an elliptic orbit. At its point of nearest approach the aircraft would ideally be at the correct height at which to commence its glide path. Since the circular orbit must be well outside the densest layers of the atmosphere, we cannot look to obtain the required retardation aerodynamically and presumably the installation of braking-rockets would be necessary. They need not, however, be very large. The

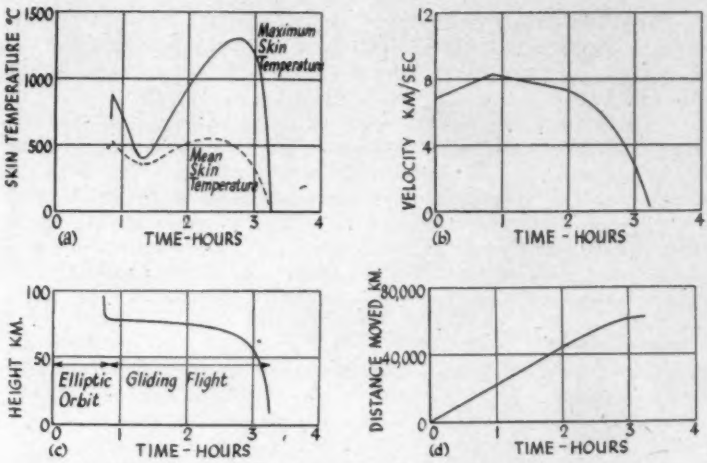

FIG. 2. Descent of aircraft of 30 Kg./Sq.m. wing loading, and of 20 tonnes all-up weight.

energy to be subtracted per unit mass, in changing from a circular orbit at a height aR above the earth's surface to an elliptic orbit tangential to the surface is

$$\frac{agR}{2\,(1+a)\,(2+a)}$$

where g is the gravitational acceleration at the Earth's surface and R is the Earth's radius. This implies a reduction in velocity of about $2a$ Km./sec. in the circular orbit: e.g. some 400 m./sec. in a circular orbit at 0.2 R from the surface. Such a velocity reduction is, of course, well within the capacity of quite a small rocket unit. In any event, the weight of its propellants would not enter into the definition of payload already made, since they would have been used before the glide.

Once it reaches the point of closest approach to the earth, the aircraft will have to be held in level flight by a lifting force from its wings directed *towards* the Earth. Its speed at this instant will be given by

$$\sqrt{gR\left[\frac{2\,(1+a)}{2+a}\right]}$$

which is more than the circling velocity near the Earth's surface—it exceeds it in fact by about a fraction $1/4a$. It follows (for instance, using the data of para. 5) that the maximum temperature on the wing *upper* surface is some $(107a^{1/4})$ per cent. of that reached by the under-surface in the subsequent glide to Earth. Remembering that a temperature of 87 per cent. of that reached on the lower surface has already been envisaged in considering the reinforcement needed to the wing structure, this initial pull-out into level flight presents no new difficulties then, if the circling orbit is within 0·4 R of the Earth.

12. The Glide Path

What happens in the glide path is largely in the hands of the pilot. However, we have suggested certain limitations: the indicated air speed should not exceed the limit stipulated in para. 8, and yet it should not be so low that a wing angle of attack of much more than 10° is required. A descent at a constant indicated air speed therefore seems appropriate. The complete trajectory of such a descent of an aircraft (with a wing loading of 30 Kg./sq.m., and the wing design already detailed) gliding to Earth at a constant indicated air speed of 60 m./sec. is shown in Fig. 2. It is assumed that the aircraft is moving in such a way that its ground course is a great circle: the effects of the Earth's rotation are ignored. The total time occupied in the descent is some 3½ hours, during which the Earth is encompassed twice.

13. Conclusions

(i) It appears that, provided the wings are suitably reinforced and made of special steel, capable of providing strength even when at 1,300° C., an aircraft carrying about five tonnes of payload can undertake a descent from a circular orbit without the assistance of braking-rockets.

(ii) A low-wing loading of 30 Kg./sq.m. would be necessary for such an aircraft, in order to keep the skin temperatures down. As a result an all-wing design with something like a delta-planform is probably most suitable: the wing thickness and aspect ratio would both have to be small, by present-day standards.

(iii) A valuable ecomony in weight can be brought about by limiting the indicated air speed during descent to a value as small as reasonable. This relieves the flutter loads acting during descent, and the wing stiffness requirements.

(iv) It then appears that structure—and in particular the wing—would account for 75 per cent. of the all-up weight (of 20 tonnes) of such an aircraft.

(v) In the absence of more suitable skin materials than steel, the transport of much heavier payloads than this to earth would seem a most difficult problem. However, lighter payloads would present less difficulty.

(vi) The reinforcement to the wing, necessary to strengthen those parts of it subjected to a high temperature, would account possibly for 10 per cent. of the weight of a 20 tonne aircraft.

(vii) Although in certain conditions skin conductivity is the determining factor, it appears that the limit to the skin temperatures reached in the presence of a boundary layer at high flight speeds is more often determined by considering the molecular structure of the airflow—in particular, the effects of surface slip.

(viii) The discussion of this paper is restricted mainly to the study of a gradual descent, at a low indicated speed. There exists a possibility that a more rapid descent, using dive brakes designed to provide a retardation of about 5 g, might be more suitable.

METEOR HAZARDS TO SPACE-STATIONS

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ABSTRACT

The analysis of Grimminger is summarized, and possible astronomical factors affecting its validity examined. The existence of iron meteors is shown to require a reduction in Grimminger's collision times by a factor of about 2. Radar observations provide direct evidence for the assumed number of meteors/magnitude relationship down to magnitude 7; extrapolation beyond this limit is uncertain because of the removal of smaller meteors by the Poynting–Robertson effect. The Poynting–Robertson effect may *increase* Grimminger's times by a factor of about 3, although a much more drastic increase due to this effect cannot be ruled out. The danger from meteor showers, including the daylight streams detected by radar, is shown to be comparable with that from sporadic meteors. Contrary to published statements, the discovery of micro-meteorites does not demand any alteration to the statistics. The greatest uncertainty in the estimates of collision times occurs in the imperfect knowledge of the mass of a meteor of given magnitude; errors in theory here may require, at the worst, a decrease in collision times by a factor of 50.

For space station lifetimes of more than one year, it is concluded that either a heavily-armoured hull or a "meteor bumper" will be required.

Introduction

The possibility of puncture through collision with meteors is one of the hazards to which a space station is exposed. It is the purpose of this paper to summarize the information which is available on this danger, and to examine the limitations and possible inaccuracies which may be inherent in our present imperfect state of knowledge. The problem has been considered before by the present author[12] and more completely by Grimminger.[5] It should be made clear at once that little improvement can be made on Grimminger's results, which may be taken as a fairly reliable guide to the dangers of collision with meteors. It is the concern of the present paper to examine possible sources of uncertainty in Grimminger's predictions, rather than to attempt a more reliable estimate.

The problem falls into two distinct parts. The first is the structural problem of calculating the penetration of a meteor of given mass, size and velocity; this involves an extrapolation from the experimental data in the ballistics range of velocities of the order of 4,000 ft./sec. to meteor velocities of the order of 200,000 ft./sec. The second is the astronomical problem of calculating the space densities of meteors of various masses and sizes in different circumstances; this involves an appeal to theoretical considerations as yet incompletely proved for estimating meteor masses, and an extrapolation from observed meteor data to much fainter and smaller meteors for the estimate of numbers of meteors. Both these extrapolations must involve considerable uncertainties.

The structural problem

The present author is not competent to discuss the structural problem. Grimminger's conclusions are thus accepted without discussion of their limita-

A paper read to the Second International Congress on Astronautics in London, September 7, 1951.

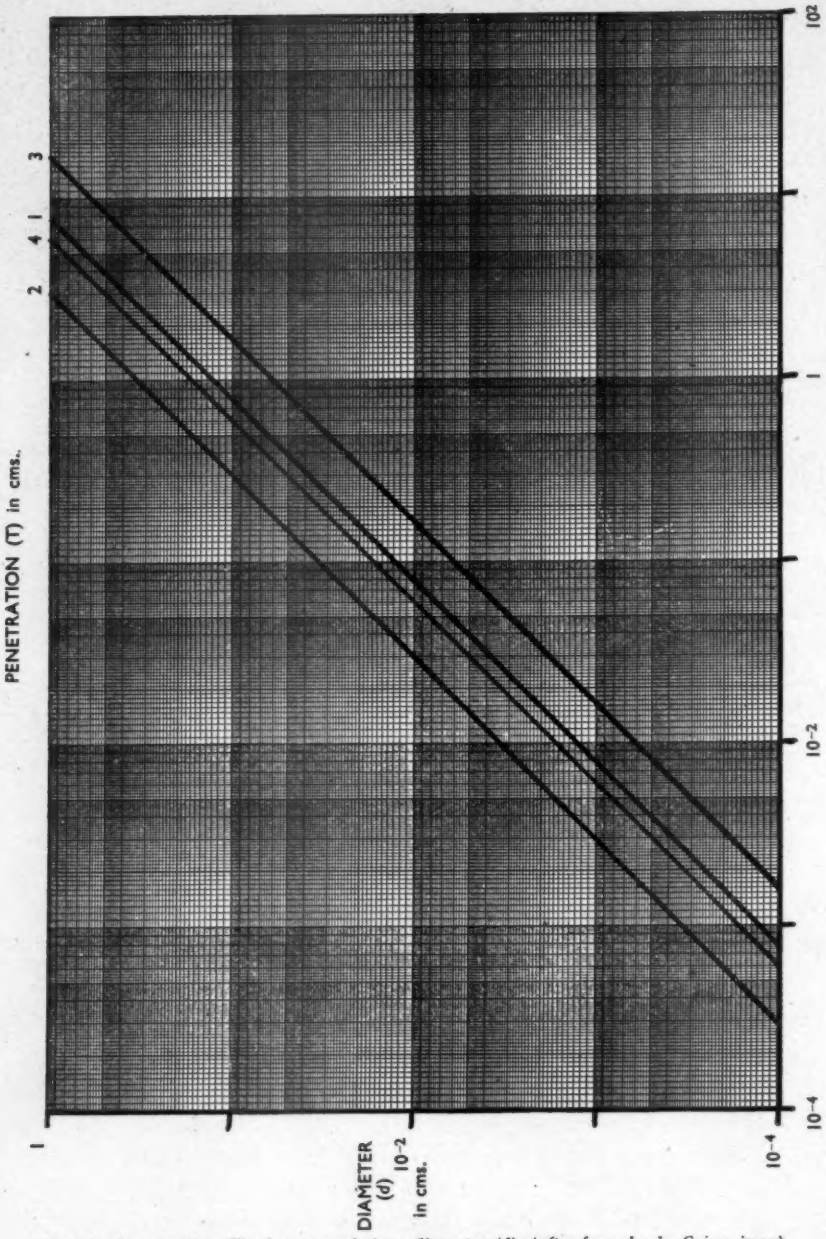

FIG. 1. Penetration (T) of meteor of given diameter (d). (*after formulae by Grimminger*)

(1) Dural hull, stony meteor.
(2) Steel hull, stony meteor.
(3) Dural hull, iron meteor.
(4) Steel hull, iron meteor.

tions. Of his data on penetration, Grimminger remarks: "Although the penetration formulas are based on ideas of a somewhat qualitative nature, and upon the extrapolation of rather meagre ballistic data to the small sizes of meteorites, it is believed that the results may serve to give an indication of the order of magnitude of the penetration resulting from impact."

For convenience, a summary of Grimminger's results are given here. A more detailed summary has been given in this *Journal* by Clarke.[3]

The penetration T of a meteor of diameter d has been given by Grimminger as

$$T = [1{\cdot}62 \log_e(V_i/5{,}000) + 1{\cdot}10]d \text{ for dural} \quad .. \quad .. \quad (1)$$

and

$$T = [0{\cdot}58 \log_e(V_i/5{,}000) + 0{\cdot}55]d \text{ for stainless steel} \quad .. \quad (2)$$

where V_i is the velocity (in ft./sec.) with which the meteor first strikes the hull of the space station, and the meteor is of the stony variety, with density 3·4 grm./c.c. Grimminger does not give the data for iron meteors, density 8·0, which he neglects as being relatively too infrequent, but his formulae reduce to the following for iron meteors:

$$T = [3{\cdot}82 \log_e(V_i/5{,}000) + 1{\cdot}10]d \text{ for dural} \quad .. \quad .. \quad (3)$$

and

$$T = [1{\cdot}35 \log_e(V_i/5{,}000) + 0{\cdot}55]d \text{ for stainless steel} \quad .. \quad (4)$$

Grimminger plots (1) and (2) for a mean value (150,000 ft./sec.) and a maximum value (250,000 ft./sec.) of V_i, but as the results are insensitive to V_i, only the maximum value, equivalent to 76 km./sec., is used here. With this value the equations reduce to:

$$T = 7{\cdot}44\,d \quad .. \quad .. \quad .. \quad .. \quad .. \quad (1')$$

$$T = 2{\cdot}81\,d \quad .. \quad .. \quad .. \quad .. \quad .. \quad (2')$$

$$T = 16{\cdot}01\,d \quad .. \quad .. \quad .. \quad .. \quad .. \quad (3')$$

$$T = 5{\cdot}82\,d \quad .. \quad .. \quad .. \quad .. \quad .. \quad (4')$$

These equations are plotted in Fig. 1. The plot of T against d is given rather than T against meteor magnitude M as displayed by Grimminger, because of the uncertainty of mass of a meteor of given magnitude, and of the two different types of meteor (stony and iron) considered.

Observational basis of Grimminger's data

The number of meteors of a given magnitude striking the Earth in a period of 24 hours is given in Table I. It is based on visual observations[19] which are reliable down to magnitude 3. It is possible, however, to estimate the inefficiency of visual observations for magnitudes 3 to 5, and when correction is made for this, the true number in this range is obtained. The figures refer to sporadic meteors; these form the largest part of the total number of visual meteors striking the Earth, but owing to the existence of daylight streams, meteor showers may be significant for the present problem. The effect of showers is considered later in this paper. Down to magnitude 5, visual observations indicate that each magnitude increase multiplies the number of meteors by 2·5. This law is used to extrapolate to magnitude 30. The total

TABLE I

Visual mag., M	Observed No.	True No., n	Σn_M^{-3}	Mass in grm., m	Diameter in cm., d	
					Stony, $\rho = 3{\cdot}4$	Iron, $\rho = 8{\cdot}0$
−3	28,000	$2{\cdot}8\times10^{4}$	$2{\cdot}8\times10^{4}$	4·0	1·30	$9{\cdot}75\times10^{-1}$
−2	71,000	$7{\cdot}1\times10^{4}$	$9{\cdot}9\times10^{4}$	1·6	$9{\cdot}66\times10^{-1}$	$7{\cdot}25\times10^{-1}$
−1	180,000	$1{\cdot}8\times10^{5}$	$2{\cdot}8\times10^{5}$	$6{\cdot}3\times10^{-1}$	$7{\cdot}07\times10^{-1}$	$5{\cdot}30\times10^{-1}$
0	450,000	$4{\cdot}5\times10^{5}$	$7{\cdot}3\times10^{5}$	$2{\cdot}5\times10^{-1}$	$5{\cdot}20\times10^{-1}$	$3{\cdot}90\times10^{-1}$
1	1,100,000	$1{\cdot}1\times10^{6}$	$1{\cdot}9\times10^{6}$	$1{\cdot}0\times10^{-1}$	$3{\cdot}83\times10^{-1}$	$2{\cdot}87\times10^{-1}$
2	2,800,000	$2{\cdot}8\times10^{6}$	$4{\cdot}7\times10^{6}$	$4{\cdot}0\times10^{-2}$	$2{\cdot}81\times10^{-1}$	$2{\cdot}11\times10^{-1}$
3	6,400,000	$7{\cdot}1\times10^{6}$	$1{\cdot}2\times10^{7}$	$1{\cdot}6\times10^{-2}$	$2{\cdot}08\times10^{-1}$	$1{\cdot}56\times10^{-1}$
4	9,000,000	$1{\cdot}8\times10^{7}$	$3{\cdot}0\times10^{7}$	$6{\cdot}3\times10^{-3}$	$1{\cdot}52\times10^{-1}$	$1{\cdot}14\times10^{-1}$
5	3,600,000	$4{\cdot}5\times10^{7}$	$7{\cdot}5\times10^{7}$	$2{\cdot}5\times10^{-3}$	$1{\cdot}12\times10^{-1}$	$8{\cdot}40\times10^{-2}$
6		$1{\cdot}1\times10^{8}$	$1{\cdot}9\times10^{8}$	$1{\cdot}0\times10^{-3}$	$8{\cdot}24\times10^{-2}$	$6{\cdot}18\times10^{-2}$
7		$2{\cdot}8\times10^{8}$	$4{\cdot}7\times10^{8}$	$4{\cdot}0\times10^{-4}$	$6{\cdot}05\times10^{-2}$	$4{\cdot}54\times10^{-2}$
8		$7{\cdot}1\times10^{8}$	$1{\cdot}2\times10^{9}$	$1{\cdot}6\times10^{-4}$	$4{\cdot}48\times10^{-2}$	$3{\cdot}37\times10^{-2}$
9		$1{\cdot}8\times10^{9}$	$3{\cdot}0\times10^{9}$	$6{\cdot}3\times10^{-5}$	$3{\cdot}29\times10^{-2}$	$2{\cdot}39\times10^{-2}$
10		$4{\cdot}5\times10^{9}$	$7{\cdot}5\times10^{9}$	$2{\cdot}5\times10^{-5}$	$2{\cdot}42\times10^{-2}$	$1{\cdot}83\times10^{-2}$
15		$4{\cdot}5\times10^{11}$	$7{\cdot}5\times10^{11}$	$2{\cdot}5\times10^{-7}$	$5{\cdot}20\times10^{-3}$	$3{\cdot}90\times10^{-3}$
20		$4{\cdot}5\times10^{13}$	$7{\cdot}5\times10^{13}$	$2{\cdot}5\times10^{-9}$	$1{\cdot}20\times10^{-3}$	$9{\cdot}00\times10^{-4}$
25		$4{\cdot}5\times10^{15}$	$7{\cdot}5\times10^{15}$	$2{\cdot}5\times10^{-11}$	$2{\cdot}42\times10^{-4}$	$1{\cdot}83\times10^{-4}$
30		$4{\cdot}5\times10^{17}$	$7{\cdot}5\times10^{17}$	$2{\cdot}5\times10^{-13}$	$5{\cdot}20\times10^{-5}$	$9{\cdot}00\times10^{-6}$

TABLE II

Magnitude, M	$\frac{1}{n_1}$	T (0·5) hours	T (0·99) hours	T (0·999) hours
−3	$5{\cdot}36\times10^{9}$	$3{\cdot}72\times10^{9}$	$5{\cdot}39\times10^{7}$	$5{\cdot}37\times10^{6}$
0	$2{\cdot}09\times10^{9}$	$1{\cdot}45\times10^{9}$	$2{\cdot}10\times10^{6}$	$2{\cdot}09\times10^{5}$
5	$2{\cdot}04\times10^{6}$	$1{\cdot}41\times10^{6}$	$2{\cdot}05\times10^{4}$	$2{\cdot}04\times10^{3}$
8	$1{\cdot}29\times10^{5}$	$8{\cdot}95\times10^{4}$	$1{\cdot}30\times10^{3}$	$1{\cdot}29\times10^{2}$
10	$2{\cdot}04\times10^{4}$	$1{\cdot}41\times10^{4}$	$2{\cdot}05\times10^{2}$	$2{\cdot}04\times10$
12	$3{\cdot}23\times10^{3}$	$2{\cdot}24\times10^{3}$	$3{\cdot}24\times10$	3·23
14	$5{\cdot}11\times10^{2}$	$3{\cdot}58\times10^{2}$	5·18	$5{\cdot}16\times10^{-1}$
16	$8{\cdot}10\times10$	$5{\cdot}62\times10$	$8{\cdot}14\times10^{-1}$	$8{\cdot}11\times10^{-2}$
18	$1{\cdot}29\times10$	8·95	$1{\cdot}30\times10^{-1}$	$1{\cdot}29\times10^{-2}$
20	2·04	1·41	$2{\cdot}05\times10^{-2}$	$2{\cdot}04\times10^{-3}$
22	$3{\cdot}23\times10^{-1}$	$2{\cdot}24\times10^{-1}$	$3{\cdot}24\times10^{-3}$	$3{\cdot}23\times10^{-4}$
24	$5{\cdot}11\times10^{-2}$	$3{\cdot}58\times10^{-2}$	$5{\cdot}18\times10^{-4}$	$5{\cdot}16\times10^{-5}$
26	$8{\cdot}10\times10^{-3}$	$5{\cdot}62\times10^{-3}$	$8{\cdot}14\times10^{-5}$	$8{\cdot}11\times10^{-6}$
28	$1{\cdot}29\times10^{-3}$	$8{\cdot}95\times10^{-4}$	$1{\cdot}30\times10^{-5}$	$1{\cdot}29\times10^{-6}$
30	$2{\cdot}04\times10^{-4}$	$1{\cdot}41\times10^{-4}$	$2{\cdot}05\times10^{-6}$	$2{\cdot}04\times10^{-7}$

number of meteors above a given magnitude level is then calculated, and given as Σn in the table. The meteor masses are calculated from the standard theory (see later), and diameters calculated for densities of 3·4 grm./c.c. (stony meteors) and 8·0 grm./c.c. (iron meteors).

Grimminger's results

On the assumption (valid for sporadic meteors) that the directions of arrival of the meteors are distributed at random, the collision probabilities for a space

station of exposed area 1,000 sq. ft. in the vicinity of the Earth are calculated. In Table II are extracted the following probabilities:

$1/n_1$ = Average number of hours between collisions.
T (0·5) hours = time interval for a 50–50 chance of no collision.
T (0·99) " = " " 100–1 " "
T (0·999) " = " " 1,000–1 " "

with a meteor larger than various upper magnitude limits.

Examination of factors possibly modifying the above data

(i) *The existence of iron meteors.* On the basis of the statistics of meteorites recovered after penetrating the Earth's atmosphere, it is believed that the stony meteors (containing some 36 per cent. oxygen, 26 per cent. iron and 18 per cent. silicon) outnumber the iron meteors (91 per cent. iron, 8 per cent. nickel) by a factor of about 10 to 1.[19] However, owing to their higher density, the iron meteors of a given magnitude are as effective in puncturing the space station hull as stony meteors of some two magnitudes brighter [see Fig. 1]. The total number of meteors above a given magnitude limit increases by a factor of about 6½ for every two magnitudes, and thus the number of meteors *effective* for a given strength of hull is about equally divided between stony and iron types. Since Table II is calculated for stony meteorites only, the times there given should be *decreased* by a factor of about 2. This assumes that the dual composition of meteorites is reflected in the composition of the much smaller meteors.

(ii) *The validity of the number of meteors/magnitude relationship.* The number of meteors of a given magnitude is directly observable visually over a range of about five magnitudes only, although it has to be extrapolated a further twelve magnitudes to reach the limiting sizes significant for the present investigation. The extrapolation is clearly open to considerable uncertainty. The development of radar techniques of meteor observation can extend the directly observed numbers down to magnitude 7 or 8.[10] The indications are that the same law of number/magnitude distribution is applicable to the range of meteor sizes which can be observed by radar, but the exact comparison of radar and visual meteor observations is still somewhat difficult owing to the completely different samples of meteors which the two methods take, the radar method detecting only those meteors whose path is at right angles to the line joining the radar receiver to the meteor. The meteor numbers can thus be said to have some observational basis down to magnitude 7.

(iii) *The Poynting–Robertson effect.* The extrapolation of numbers beyond magnitude 7 can be valid only provided no physical process intervenes to disturb the distribution. However, such processes do exist, and it is not easy to allow for their effects.

One such process is the pressure of radiation from the Sun. According to Watson, all meteors smaller than magnitude 30 would be repelled out of the solar system by radiation pressure; this is the reason why Table I is not extended beyond magnitude 30. The limiting magnitude for radiation pressure effects

is too great to be of significance here. Another process, affecting much larger meteors, is the Poynting–Robertson effect.

Following earlier work by Poynting,[16] Robertson showed[18] that the effect of absorption and subsequent emission of solar radiation by an isolated particle in the solar system is to introduce a resisting force proportional to the velocity of the particle, producing a slow secular decrease in the size of the particle orbit until the particle eventually falls into the Sun.

The Poynting–Robertson effect has been applied to the study of meteor orbits by Wyatt and Whipple.[24] They conclude that in a time short compared with the age of the solar system, all particles of diameter less than 0·08 cm. which had orbits of small size of the asteroidal type, would have been swept into the Sun. Hence any meteors fainter than about fifth magnitude must have come from great distances from the Sun, and be travelling in either hyperbolic orbits, and hence are of interstellar origin, or else in orbits of great eccentricity and large semi-major axis, similar to the cometary orbits. It is, therefore, necessary to make an estimate of the proportion of sporadic meteors which have such hyperbolic or cometary orbits.

It is not possible, on the basis of visual observations, to decide whether a given meteor has a cometary or hyperbolic orbit, but on the basis of statistical work with certain assumptions, it was believed for many years that a high proportion (about 60 per cent.) of visual sporadic meteors were interstellar [for summary, see reference 15]. There were, however, indications that the assumptions made were incorrect, and the development of accurate radar methods of measuring meteor velocities has proved conclusively that if any interstellar meteors exist, they cannot number more than about 1 per cent. of the visually-observed sporadic meteors.[1,10,11] An examination of the properties of the absorbing interstellar dust clouds also suggests that the number of interstellar meteors visually observable is negligible.[14]

To estimate the proportion of sporadic meteors in cometary orbits is not possible without some knowledge of the origin of these bodies. There is some reason to believe that, while shower meteors have a definite association with comets, sporadic meteors have a common origin with meteorites, which are almost certainly planetary debris, moving in small, low-eccentricity orbits. Whatever the origin of the sporadic meteors, a dropping-off of numbers of meteors due to the Poynting–Robertson effect as the magnitude is increased beyond 5 is to be expected, becoming very rapid at great magnitudes. It would probably be not unrealistic to suggest a decrease in the numbers of meteors smaller than magnitude 10 by a factor of 3. This would have the effect of *increasing* the times given in Table II by the same factor, in that part of the table dealing with meteors smaller than magnitude 10. Should all the sporadic meteors be associated with meteorites and asteroids, and hence move in small orbits, then the total number of meteors, Σn in Table I, should not increase below about magnitude 7, and the times of Table II should therefore be multiplied, in the critical regions of magnitudes 11–15, by factors of the order of 10^4.

(iv) *Micro-meteorites.* After the great Giacobinid shower of 1946, a number of small magnetic particles which were wedged-shaped and opaque

were found, apparently associated with the shower, by Landsberg.[9] Such micro-meteorites must have been stopped by the atmosphere without being heated above their melting-points. The mechanism of interaction of such micro-meteorites and the atmosphere has been examined by Whipple.[22,23]

It has been suggested[6] that the discovery of these micro-meteorites will require a more pessimistic estimate of the chance of collision with a space station than has hitherto been made. "The position as to meteorites had altered for the worse owing to the discovery by Whipple of 'micro-meteorites' which do not flare up to become visible in our atmosphere, but whose presence is revealed by radar observations. Although these objects might not penetrate the metal skin of the ship, their contact with the windows might prove awkward." This is, in fact, a misconstruction of the situation. The particles discovered by Landsberg have diameters of only about 50 microns, and any meteoric particles traversing the atmosphere undamaged must be of this order of size. Such meteors correspond to visual magnitudes of about 15 (Table I), could not be observed by radar methods, and would, even if rendered luminous by the atmosphere, be much too faint to be visible. Furthermore, the fact that the body is not heated to its melting-point depends upon the properties of the Earth's atmosphere, and has nothing to do with the distribution of particle size in the meteor community. Hence the existence of micro-meteorites in no way invalidates the extrapolation of meteor numbers on which the prediction of collision probability depends; if it were possible by any means to observe meteors down to magnitude 30, there would, due to this micro-meteorite effect, merely be an *apparent* falling off of the number of meteors in each successive magnitude range, as against the factor of 2·5 found for the brighter meteors, which was not real in terms of meteor masses.

(v) *Meteor masses.* The greatest uncertainty in this investigation lies in the estimate of the mass of a meteor of given magnitude. Since the deceleration of a meteor by the atmosphere is small, the total light intensity of the meteor at any time, I, will be given by:

$$I = \tfrac{1}{2}\tau \dot{m} v^2 \qquad (5)$$

where τ represents the fraction of the total dissipated energy which is radiated in visual wavelengths. A value of τ can be found only by an appeal to theoretical considerations.

On quite general grounds, it is to be expected that nearly all the kinetic energy of the meteor will be converted directly into heat, a small fraction into visible radiations and a still smaller fraction into the production of ions.[7] The most satisfactory theoretical treatment is that of Öpik,[12] and it is from this theory that meteor masses are at present calculated. Öpik's theory suggests that about 1 per cent. of the kinetic energy is transformed into visible radiation, the ratio of heat/light/ionization being about $10^4 : 10^2 : 1$.[7]

The matter is complicated by the fact that τ is a function of the meteor velocity; Öpik suggests a law

$$\tau = \tau_0 v \qquad (6)$$

but this law is far from being firmly established, although the Harvard–Massachusetts Photographic Meteor Programme is attempting an experimental

TABLE III. METEOR SHOWERS

Name	Date of maximum	Mean hourly rate at max.	$\Sigma_M^{-3} n$ for one observer per hour		Duration (days)	$\Sigma_M^{-3} n$ for one observer for whole shower		$\Sigma_M^{-3} n$ colliding with space station during shower	
			M = 11	M = 14		M = 11	M = 14	M = 11	M = 14
NOCTURNAL									
Quadrantids ..	Jan. 3	100[r]	$6{\cdot}3\times10^{4}$	$1{\cdot}0\times10^{6}$	2	$3{\cdot}0\times10^{8}$	$4{\cdot}8\times10^{7}$	0·047	0·75
Lyrids	April 21	10[v]	$6{\cdot}3\times10^{3}$	$1{\cdot}0\times10^{5}$	2	$3{\cdot}0\times10^{5}$	$4{\cdot}8\times10^{6}$	0·005	0·08
Perseids ..	Aug. 12	50[v]	$3{\cdot}1\times10^{4}$	$5{\cdot}0\times10^{5}$	12	$8{\cdot}9\times10^{6}$	$1{\cdot}4\times10^{8}$	0·14	2·2
Giacobinids ..	Oct. 10	1,400[r]	$8{\cdot}8\times10^{5}$	$1{\cdot}4\times10^{7}$	0·2*	$4{\cdot}4\times10^{6}$	$7{\cdot}0\times10^{7}$	0·069	1·1
Orionids ..	Oct. 19	15[v]	$9{\cdot}5\times10^{3}$	$1{\cdot}5\times10^{5}$	10	$2{\cdot}4\times10^{6}$	$3{\cdot}6\times10^{7}$	0·037	0·56
Taurids	Nov. 3–10	10[v]	$6{\cdot}3\times10^{3}$	$1{\cdot}0\times10^{5}$	27	$4{\cdot}1\times10^{6}$	$6{\cdot}5\times10^{7}$	0·064	1·0
Leonids ..	Nov. 16	10[v]	$6{\cdot}3\times10^{3}$	$1{\cdot}0\times10^{5}$	5†	$7{\cdot}5\times10^{5}$	$1{\cdot}2\times10^{7}$	0·012	0·19
Geminids ..	Dec. 12	60[v]	$3{\cdot}8\times10^{4}$	$6{\cdot}0\times10^{5}$	5	$4{\cdot}6\times10^{6}$	$7{\cdot}2\times10^{7}$	0·072	1·1
Ursids	Dec. 22	10[v]	$6{\cdot}3\times10^{3}$	$1{\cdot}0\times10^{5}$	1	$1{\cdot}5\times10^{5}$	$2{\cdot}4\times10^{6}$	0·002	0·04
DAYLIGHT									
η-Aquarids ..	May 4	10[r]	$6{\cdot}3\times10^{3}$	$1{\cdot}0\times10^{5}$	10	$1{\cdot}5\times10^{6}$	$2{\cdot}4\times10^{7}$	0·023	0·37
Piscids	May 7	30[r]	$1{\cdot}9\times10^{4}$	$3{\cdot}0\times10^{5}$	9	$4{\cdot}1\times10^{6}$	$6{\cdot}5\times10^{7}$	0·064	1·0
Arietids ..	June 4	60[r]	$3{\cdot}8\times10^{4}$	$6{\cdot}0\times10^{5}$	6	$5{\cdot}5\times10^{6}$	$8{\cdot}6\times10^{7}$	0·086	1·3
ξ-Perseids ..	June 6	40[r]	$2{\cdot}6\times10^{4}$	$4{\cdot}0\times10^{5}$	15	$9{\cdot}6\times10^{6}$	$1{\cdot}4\times10^{8}$	0·14	2·2
54-Perseids ..	June 26	30[r]	$1{\cdot}9\times10^{4}$	$3{\cdot}0\times10^{5}$	8	$3{\cdot}6\times10^{6}$	$5{\cdot}7\times10^{7}$	0·056	0·89
β-Taurids ..	July 3	40[r]	$2{\cdot}6\times10^{4}$	$4{\cdot}0\times10^{5}$	10	$6{\cdot}0\times10^{6}$	$9{\cdot}6\times10^{7}$	0·094	1·5
α-Orionids ..	July 12	50[r]	$3{\cdot}1\times10^{4}$	$5{\cdot}0\times10^{5}$	5	$3{\cdot}7\times10^{6}$	$6{\cdot}0\times10^{7}$	0·058	0·94
ν-Geminids ..	July 12	60[r]	$3{\cdot}8\times10^{4}$	$6{\cdot}0\times10^{5}$	5	$4{\cdot}6\times10^{6}$	$7{\cdot}2\times10^{7}$	0·069	1·1
λ-Geminids ..	July 12	30[r]	$1{\cdot}9\times10^{4}$	$3{\cdot}0\times10^{5}$	5	$2{\cdot}3\times10^{6}$	$3{\cdot}6\times10^{7}$	0·036	0·60
θ-Aurigids ..	July 25	20[r]	$1{\cdot}3\times10^{4}$	$2{\cdot}0\times10^{5}$	11	$3{\cdot}4\times10^{6}$	$5{\cdot}3\times10^{7}$	0·053	0·83
					Total colliding (1 year)			1·13	17·8

* Giacobinids show appreciable display only occasionally (about once in every 12 years).

† Leonids show occasional concentrated displays (periodicity 33 years?). Hourly rate given is the normal one.

Symbols [r] = hourly rate from radar observations. [v] = hourly rate from visual observations.

Sources Daylight streams: All data from Aspinall, Clegg and Lovell, *M.N.R.A.S.*, **109**, 352, 1949.
Hourly rates: Visual, from Meteor Diaries, *B.A.A. Handbooks*, 1945–50.
Radar, Quadrantids; *B.A.A. Handbook*, 1949, page 61.
Radar, Giacobinids; Lovell, Banwell and Clegg, *M.N.R.A.S.*, **107**, 164, 1947.
All visual dates and durations, from *B.A.A. Handbooks*, 1945–50.

investigation of equation (6)[8,16] which will itself serve as a check on the correctness of the Öpik theory.

Quite apart from the validity of the theoretical analysis, there arises uncertainty in

(*a*) the state of the upper atmosphere, which will affect the magnitude of a meteor of given mass, and
(*b*) in the value of certain collisional cross-sections and other atomic data on which the predictions depend,

since these atomic constants were calculated by Öpik on a combination of wave-mechanical considerations and the diameters of electron orbits on the old quantum theory, and may require drastic revision in the light of the later developments of atomic theory.

The meteor mass is obtained by backward integration from the point of disappearance of the meteor, t_e, assuming equations (5) and (6), thus giving:

$$m = (2/\tau_o)\int_t^{t_e}(I/v^3)dt \qquad .. \quad .. \quad .. \quad .. \quad .. \quad (7)$$

It would seem reasonable to suppose that the masses derived from equation (7), using Öpik's value for τ, should not be in error by more than a factor of 10. Thus, to allow for possible underestimates in meteor masses, Table II should be entered at a magnitude three magnitudes *greater* than that indicated in Table I; this represents a decrease in collision probability times by a factor of about 50.

The use of artificial meteors of known mass and velocity ejected from high-altitude rockets was suggested by Zwicky[35] as a means of checking the theory of meteor masses. However, so far experiments of this type have not proved successful, partly due to instrumental failures and partly due to the small masses and low velocities of the ejected particles.[20]

The effect of meteor showers

The statistics of numbers of meteors given in Table I is essentially of sporadic meteors, since the proportion of meteors which are members of well-defined visual showers is small. However, with the inclusion of the daylight streams, showers might prove a potential danger to a space station.

Table III shows the properties of the major meteor showers encountered by the Earth; no knowledge can as yet be obtained of meteor showers whose orbits do not intersect the orbit of the Earth. The consideration of the effects of meteor showers is therefore restricted to a space station which is a satellite of the Earth. The night-time showers were recognized by visual observers; the daylight streams have been discovered recently by radar methods of observation.[2,4,17] The hourly rates are obtained from either visual (v) or radar (r) observations; the two sets of figures are roughly comparable since the increased sensitivity of the radar method is almost exactly off-set by its selectivity of meteors with respect to their flight directions.[4] The total numbers of meteors above two magnitude limits (11 and 14) are obtained by extrapolating

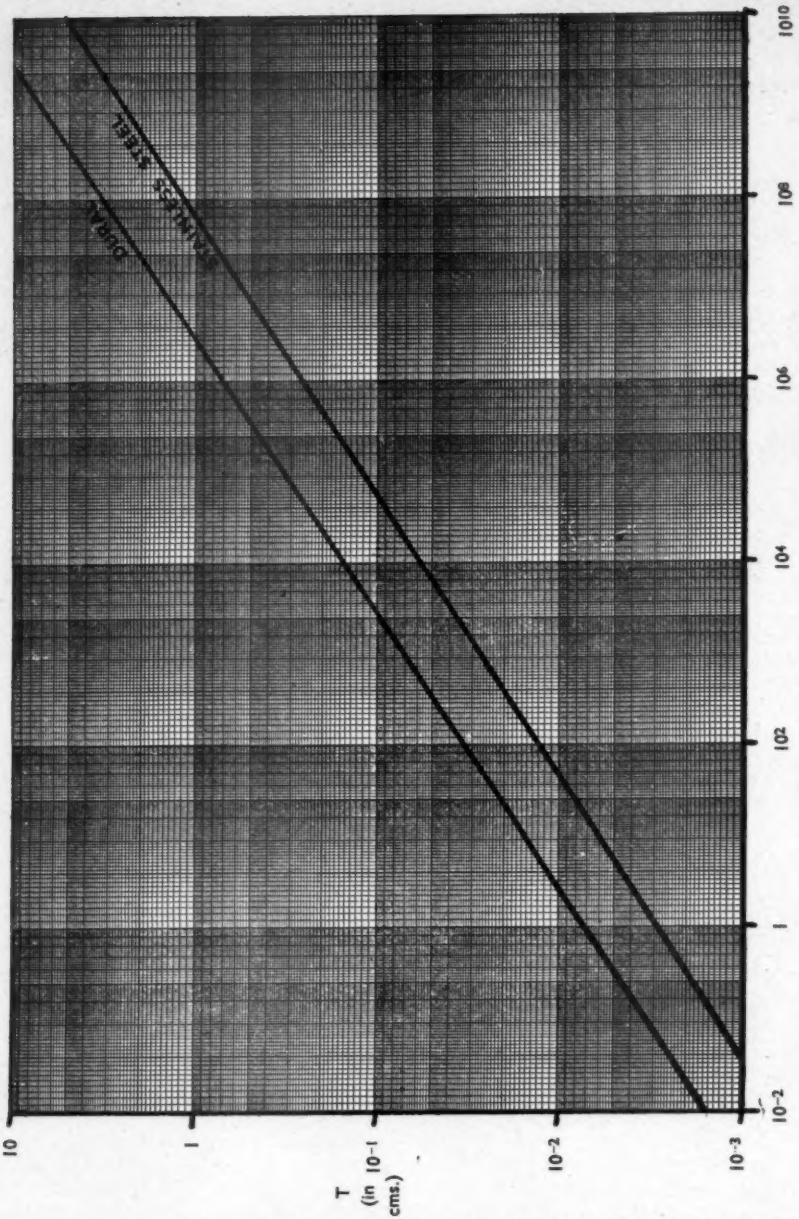

FIG. 2. Average number of hours between punctures of hull ($1/n_1$) for given hull thickness (T) for dural and stainless steel.

(The times given by Grimminger have been divided by 2 to allow for the additional danger from iron meteors.)

by the factor of 2·5 for every increase of 1 in magnitude,* assuming the hourly rates to apply to all meteors above magnitude 4 (those of magnitude 5 which are observed being off-set by those of magnitude 4 which are missed). The space densities are calculated on the assumption (rather pessimistic) that the observer sees only those meteors above points within 80 km. radius of his observing site. In the case of sporadic meteors, where the direction of arrival is assumed to be random, the velocity of the space station is not a relevant factor in the calculation of collision probability[5]; in the case of showers, the meteors arrive from a single direction only, and the relative velocity of the meteors and the space station is relevant. For a space station which is a satellite of the Earth, pursuing essentially the same orbit, the relative velocity factor is allowed for in the hourly rate and duration of the stream, and the collision probability is calculated simply by multiplying the hourly rate by the duration of the shower and the reciprocal of the ratio of the area of visibility of one observer to the cross-section of the space station. The results tabulated in the final column of Table III are pessimistic, in that the hourly rate at *maximum* is taken to apply to the whole duration of the stream. Further, streams such as the Giacobinids and possibly the Leonids, which are closely bunched along their orbits have periodicities in activities; for example, the Giacobinids are not visible except when the Earth crosses their orbit when the parent comet (Giacobini–Zinner) is close (say about once in every 12 years).

Table III shows that a space station of area 100 sq. metres (comparable with the 1,000 sq. ft. of Grimminger's example) would intercept about one shower meteor above eleventh magnitude and about twenty above fourteenth magnitude each year. The additional danger from showers is thus comparable with that from sporadic meteors.

Summary

It is thus concluded that Grimminger's tabulation of collision probabilities presents as fair a picture as is possible within the limitations of present knowledge. It is optimistic by a factor of about 2 through neglect of the contribution of the scarcer but denser iron meteors, and by a further factor of 2 through neglect of meteor showers; these may well be offset by the effects of the Poynting–Robertson effect in removing meteors fainter than about fifth magnitude, although the possibility of a much more drastic fall in the numbers of the fainter meteors due to this process cannot be ignored. The most serious defect in our present knowledge is in the calculation of meteor masses, which may introduce an error of up to a factor of 10 in mass, or about 50 in collision probability times.

Collision times and protection of the space-station

An examination of Table II suggests that while the danger of collision with a meteor is not serious for short interplanetary trips, for example, to a round lunar trip, it presents a more serious hazard to permanent orbital structures such as space stations. The degree of danger depends, of course, upon the

* Some evidence for the applicability of this size distribution to meteor showers as well as sporadic meteors is given by radar observations of the Giacobinid meteor shower, 1946 (Lovell, Banwell and Clegg, *M.N.R.A.S.*, **107**, 164, 1947).

thickness and strength of the hull, and in Fig. 2 the average number of hours between hits is plotted against hull thickness for dural and stainless steel. A lifetime of one year is seen to demand a hull thickness of 0·15 cm. dural and 0·06 cm. stainless steel.

If, as suggested by Grimminger, hull thicknesses of only 0·13 cm. are conceivable, then lifetimes of a few years are available. A possible solution to the problem of longer lifetimes was incorporated in the pre-war B.I.S. spaceship design and suggested again recently by Whipple.[21] It is to surround the vessel with a thin sheet of material to act as a meteor bumper. When a meteor collides with a thin sheet of metal of thickness comparable to its diameter, the result is a small explosion in which both the meteorite and the material of the sheet are vaporized at high temperatures. Thus a "meteor-bumper" consisting of a millimetre-thick sheet of metal surrounding the hull of the space station at a distance of about 1 inch would dissipate meteors of a size up to about sixth magnitude, and hence increase the average time between collisions to the much more tolerable figure of about 100 years. Since the only alternative as a protection against the very real hazard of meteors to a space station would seem to be heavy armour, such suggestions deserve close consideration.

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THE IMPORTANCE OF SATELLITE VEHICLES IN INTERPLANETARY FLIGHT

By Dr. Wernher von Braun

This paper has been reprinted as a special supplement to this issue of the Journal.

MINIMUM SATELLITE VEHICLES

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Introduction

One's first duty in presenting a paper of this kind is to define precisely what is meant by the term, Minimum Satellite Vehicle, as there are clearly several objectives that can be fulfilled by "minimum" rockets designed for specific experimental tasks.

In this survey, four vehicles are considered and to obtain a useful comparison between them, we have adopted the following standard parameters: height of orbit, 800 kms. (500 miles); propellant, liquid oxygen/hydrazine, specific impulse, 325 seconds. In every case, the rockets are considered as three-step vehicles, with the fourth scheme illustrating the application of Expendable-Tanks; the performance is based on a characteristic velocity of 10km./sec. Accelerations have been taken as lg. effective at take-off, rising to 6 g. at "all-burnt" for the first and second steps of Schemes A, B and C, whilst in the case of Scheme D, the variation is slightly greater as the result of expendable construction, being between 1 g. and 6·6 g. for the first step and between 1 g. and 7·25 g. for the second step. It may be pointed out that since the third steps will be firing tangentially to the Earth's surface for all these schemes and are therefore undergoing negligible "g" loss, a low acceleration may be used, which gives the dual advantage of reduced motor weight and more sensitive control of velocity towards the "all-burnt" stage.

The "Absolute Minimum Vehicle," to which we refer as Scheme A, will be designed with the primary object of projecting a body into a closed orbit with a *minimum* of controlling equipment. This experiment would be of the nature of a first approximation for checking the stability of the orbit in conjunction with tracking radar.

Scheme B may be regarded as an extension of Scheme A to allow for a *useful payload* of 100 kg. (220 lb.), sufficient for the installation of a small multiple-channel telemetering system for recording various data (e.g. cosmic radiation, ultra-violet radiation, ambient temperature, etc.).

Scheme C is basically similar to Scheme B, with additional control equipment for obtaining improved accuracy over the final path of the trajectory.

Finally, Scheme D illustrates the influence of Expendable-Tank Construction and affords a direct comparison with Scheme C in terms of variation in payload, the all-up weight and weight of control equipment being the same for both projects.

Structural Considerations

One of the first obstacles in attempting an analysis of rocket performance concerns weight estimates, for upon the accuracy of the figures derived will depend the usefulness of the survey. The weight estimates used in these studies

A paper read to the Second International Congress on Astronautics in London, September 7, 1951.

have been based on a careful breakdown of the A–4 structure and on empirical rules resulting from previous work; these have been verified for the most critical cases by stress calculations carried out on the initial steps of Scheme A and Scheme C.

At this point, some general observations on the types of construction we have envisaged may be of interest, particularly with regard to tank layout.

In the case of the first step of the Type C vehicle, the structure was considered on the basis of the A–4 configuration, in which the propellant tanks are separate from the load-carrying structure. Subsequently, we investigated the possibility of using the outer tank wall as an integral structure, strengthened by four longerons running the full length of the fuel bay, the large curved panels of the rocket's skin being stiffened by stringers and transverse frames and sealed against loss of pressure. This tank structure, which houses the fuel and oxidant within two concentrically arranged metal shells, is of annular layout. The oxidant is carried in the inner shell which is made up of two thin gauge cylinders held apart by equally spaced "Z" shaped stiffeners, the space between being insulated with glass wool. The fuel occupies the remaining space between the oxidant tank and the outer main load-carrying structure of the rocket. The tank ends are regarded as flat circular diaphragms bounded by reinforcing rings. All loads are assumed to be transferred from the diaphragms to the rings by radially disposed members, acting in much the same way as the spokes in a wheel. The diaphragms form pressure-tight bulkheads across the full section of the rocket.

It is emphasised that here we are considering an integral type of structure, there being no separate outer skin to the propellant tank. The result is that the combined tank and structure can be lighter than the conventional construction owing to additional strength obtained from pretensioning effects due to the tank pressurisation (nominal 1·76 kg./cm.^{2} (25 lb./in.^{2}).)

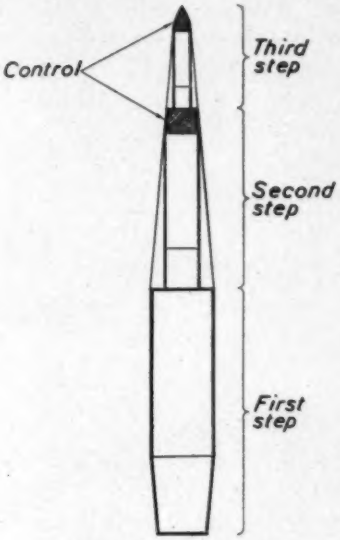
The total weight of a structure of this nature was calculated and showed a saving of approximately 8½ per cent. over the conventional A–4 type construction which we actually used as a basis for the performance calculations. A further minor variation consisted of replacing the flat tank ends with hemispherical ends, which are assumed to be suitably joined to the tank skins; this small change amounted to an additional weight economy of 2½ per cent. These figures give a small indication of how useful improvements of the structural factor can be made by careful design.

The Absolute Minimum Orbital Vehicle: Scheme A

In the case of the "Absolute Minimum Vehicle," Scheme A, there being no specific payload, size is determined entirely by the weight of control equipment required for guiding the final step into the sub-orbit.

The techniques involved in placing a vehicle into a closed orbit have already been fully dealt with elsewhere* and need not be repeated here. The method we have adopted for controlling the rocket over the final path of the trajectory is straightforward since all guidance equipment will be carried not in the final (satellite) step but in the step beneath it. The second step will

* D. F. Lawden *"The Ascent of Satellite Vehicles"* which will be published later.—Ed.



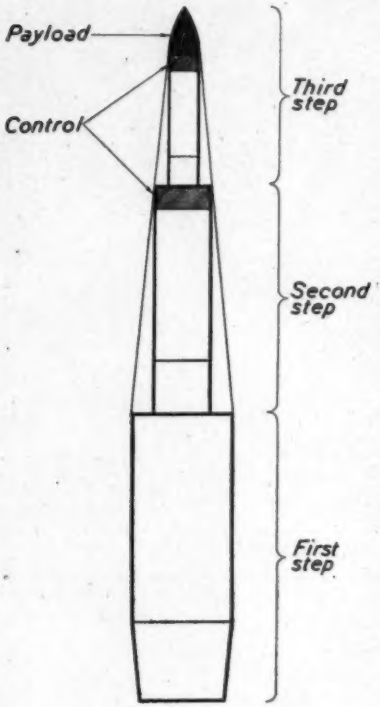
Scheme "A"			
	First step	Second step	Third step
Payload, kg.	2,880	210	—
Control, kg.	—	100	25
Structure, kg.	1,000	350	30
Pumps and motors, kg.	1,730	300	15
Propellant, kg... ..	11,190	1,920	140
All-up, kg.	16,800	2,880	210
Propellant flow, kg./sec.	108·6	18·64	0·68
Thrust, kg.	33,600	5,760	210
Firing time, seconds ..	103	103	206
Acceleration	6*g*	6*g*	3*g*
Length, metres ..	15·6	8·3	3
Diameter, metres ..	1·9	1·05	0·5
Number of motors ..	1	1	1

FIG. 1. Scheme "A"

therefore have the responsibility of controlling the trajectory until the moment of separation of the final step, the interval before separation being controlled by steam jets from the pump unit in the second step. In this way, the control system of the final step need not be capable of holding the rocket to a curved flight path as it will be aligned on a tangent relative to the Earth's surface by the second step and will require merely an inertial control, similar to that of the A–4, to prevent its axis from wandering; this would, in effect, entail a simple gyro system, in conjunction with exhaust vanes or a "pivoting motor," to correct pitch and yaw during the final period of thrust which brings the "satellite" step to true orbital velocity. Only the first and second steps will be under true guidance, all control being broken off when the third step separates.

The all-up weight of the Type A vehicle was estimated at 16·8 tonnes, the overall length being 15·6 metres (51 ft.) with a maximum diameter of 1·9 metres (6·2 ft.)—approximately the same linear dimensions as the A–4. Additional data for this project appears in Table A (fig. 1).

As the final step of the "Absolute Minimum Vehicle" will be of particularly small dimensions (3 metres long x ·5 metre in diameter), it might be possible, for a very small weight penalty, to incorporate a metalised "paper" balloon for use as a radio reflector, which could be attached to the rocket and puffed up in space. A further development of this vehicle might usefully employ a radio



Scheme "B"			
	First step	Second step	Third step
Payload, kg.	10,700	1,050	100
Control, kg.	—	100	25
Structure, kg.	3,720	1,300	150
Pumps and motors, kg.	6,430	1,110	75
Propellant, kg... ..	41,550	7,140	700
All-up, kg.	62,400	10,700	1,050
Propellant flow, kg./sec.	403	69·3	3·4
Thrust, kg.	124,800	21,400	1,050
Firing time, seconds ..	103	103	206
Acceleration	6*g*	6*g*	3*g*
Length, metres ..	20·5	12·0	5·25
Diameter, metres ..	3·0	1·7	0·9
Number of motors ..	5	1	1

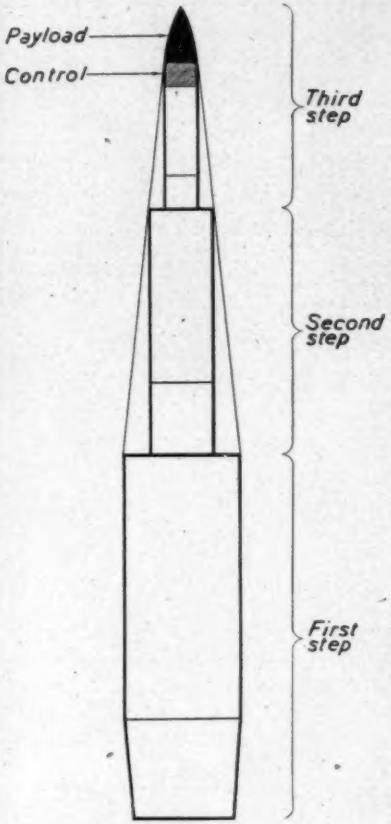
FIG. 2. Scheme "B"

beacon in the final step for position-finding, with an instrument for measuring a single quantity (e.g. cosmic ray intensity), the data being incorporated in the return signal. The American investigators, Malina and Summerfield, have suggested that such a device might be produced for a weight of 10 lb. (4·5 kg.).

Scheme B

In the second project, we have sought to illustrate the influence on the take-off mass of 100 kg. (220 lb.) of useful payload carried in the final step. The allocation of control equipment is the same as for Scheme A, 25 kg. (55 lb.) in the final step (inertial) and 100 kg. (220 lb.) in the second step for true guidance.

Due to the incorporation of payload, the all-up weight (16·8 tonnes for the previous project) has risen to 62·4 tonnes, resulting in an overall length of 20·5 metres (67 ft.) and a maximum hull diameter of three metres (10 ft.). To achieve a practical motor arrangement in the initial step, comensurate with present-day experience, the 125 tonnes thrust is assumed to be produced by five motors.



Scheme "C"			
	First step	Second step	Third step
Payload, kg.	15,600	1,680	100
Control, kg.	—	—	100
Structure, kg.	5,420	1,900	240
Pumps and motors, kg.	9,350	1,620	120
Propellant, kg.	60,530	10,400	1,120
All-up, kg.	90,900	15,600	1,680
Propellant flow, kg./sec.	587·7	101	5·4
Thrust, kg.	181,800	31,200	1,680
Firing time, seconds ..	103	103	206
Acceleration	6*g*	6*g*	3*g*
Length, metres ..	24·0	13·25	6·0
Diameter, metres ..	3·5	1·9	1·0
Number of motors ..	5	1	1

FIG. 3. Scheme "C"

Scheme C

The experience gained with satellite vehicles of larger dimensions will permit the design of orbital rockets capable of a finer degree of control than would hitherto be possible, for example, with the merely directionally guided satellite steps of Schemes A and B. The Type C vehicle, therefore, has again the 100 kg. payload of Scheme B but with an additional 75 kg. (165 lb.) of control equipment incorporated in the final step; the result is that the all-up weight (62·4 tonnes for Type B) has been increased to 91 tonnes, the overall length of the vehicle being 24 metres (79 ft.) with a maximum hull diameter of 3·5 metres (11·5 ft.).

Scheme D

The design of the final vehicle we have considered, Type D, is of a more speculative nature and its various features would not, in practice, be combined

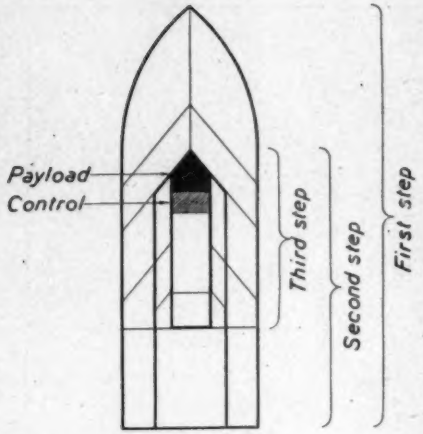


FIG. 4. Scheme "D"

SCHEME "D"			
	First step	Second step	Third step
Payload, kg.	18,300	2,670	220
Control, kg.	—	—	100
Structure, kg.	6,200	2,340	380
Motors and pumps, kg.	7,400	1,910	190
Propellant, kg. ..	59,000	11,380	1,780
All-up, kg.	90,900	18,300	2,670
Propellant flow, kg./sec.	587·7	118·5	8·6
Thrust, kg.	181,800	36,600	2,670
Firing time, seconds ..	100	96	206
Acceleration	6·6*g*	7·25*g*	3*g*
Length, metres ..	12·5	8·25	5·25
Diameter, metres ..	4·0	2·5	1·2
Expendable tank bays	3	2	—
Mass ratio actual ..	2·84	2·64	3
Number of motors ..	6	1	1

until they had been proved separately. Principally, it illustrates the influence of Expendable-Tank Construction and affords a direct comparison with the Type C Vehicle in terms of variation in payload, the all-up weight and weight of control equipment being identical with the former project.

Expendable-Construction has been the subject of certain of our previous papers. It consists of jettisoning from a rocket under thrust propellant tanks, formed as half-cylinders, which when bound together with explosive ties had acted as integral load-carrying structure and formed part of the hull of the initial steps.

Scheme D is considered as a three-step vehicle with the component steps situated one within the other. This arrangement has the advantage of decreasing the overall length and thereby reducing the bending moment and facilitating the control of the rocket. Additionally, the second step extends into the motor bay of the first step so that the central motor of the lower group is eliminated. The second step motor is thereby allowed to do useful work during the burning time of the first step instead of lying idle over that period.

The steering of the first step would probably be controlled by exhaust vanes due to the close multiple mounting of the motors. This arrangement would necessitate the locking of the "pivoting motor" of the second step until the time of separation which would occur 100 seconds after take-off. The propellant feed for the motor of the second step, during the period it is functioning as part

of the first step, will be taken from the tanks of the first step via a low-pressure boost pump through feed pipes and a non-return valve, and thence into the propellant tanks of the second step which are thus kept topped up until separation.

For the same all-up weight as the Type C vehicle (91 tonnes), the overall length of the rocket is reduced from 24 metres (78 ft.) to 12·5 metres (41 ft.), with a maximum hull diameter of 4 metres (13 ft.). It is found that improvements in the overall mass-ratio of this project will permit, for the same all-up weight and performance, an increase in weight or payload of more than double—from 100 kg. to 220 kg. (485 lb.).

Applications of Minimum Satellite Vehicles

The uses to which minimum satellite vehicles may be put are varied. Some of these uses have already been mentioned, and certainly, as an extension to the existing American high-altitude programmes, the orbital rocket will be of considerable value, for although altitudes of between 65 and 135 miles have been attained by A–4 and Viking rockets, the period of time spent above the limit of radio-sonde balloons (which is approximately 25 miles) is only about five minutes. The extension of radio-telemetering into free space will permit studies of radiations, corpuscular and electromagnetic, emanating from outer space, which will be observable for long periods without the interference of disturbing secondary effects due to the atmosphere. Perhaps most important of these is the study of cosmic ray primaries, with all the great implications to nuclear physics and our further understanding of their character of the Universe. There are, however, several other benefits to be derived from the early development of satellite vehicles, among the most obvious being the recording of the density of interplanetary gases. Such a rocket could also obtain a complete solar spectrum continuously, except when in the Earth's shadow.

Ley has suggested that the unmanned satellite rocket might even furnish data concerning the average number of impacts of meteoric dust particles, which may be less than one-tenth millimeter in diameter. Visual brightness, he points out, might provide a clue to the density of cosmic dust. If we imagine that the rocket leaves the Earth with a polished hull, its high reflection should be gradually converted to spread (and even ultimately to diffuse) reflection by the impact of tiny cosmic particles, with a corresponding change in its visual brightness. As the reflecting powers of the rocket diminish, its temperature must increase because more solar radiation will be absorbed and less of it reflected back into space. From the reduction of visual brightness, observed directly, and the increase in temperature reported by the instruments, the probable number of cosmic particles would be established within fairly reasonable limits.

Studies made in conjunction with small non-returning satellite rockets are therefore likely to have great bearing in many branches of science, with maximum benefit in the fields of astrophysics, astronomy, meteorology, radio-communication, guided-missiles and astronautics.

The Problem of Power Supply for Telemetering

Power for supplying the instruments will be a problem of its own if the vehicle is to have a useful operating life. Batteries will be useless beyond a

period measured in weeks and although we may ultimately hope to find the solution in a nuclear reactor, which might be made relatively light since shielding can be eliminated,* our early schemes may conceivably rely on the fact that a temperature differential will exist between the sunward side of the rocket and the side in shadow, so that the application of thermo-elements as a source of power is a distinct possibility—enabling perhaps short transmissions to take place separated by fairly long intervals. Alternatively, we may find a solar generator more suitable for the purpose, whereby solar heat is concentrated by means of a concave mirror on to a closed system of pipes containing a volatile fluid. Boiling of the liquid by the trapped solar energy would serve to operate a small turbo-generator. It remains to be seen how lightly such units can be constructed but it appears unlikely that solar generators can be used in the smallest types of satellite rocket. It might be pointed out, however, that power would need to be sufficient to work the instruments only for certain limited periods and that the energy available from the generator could be stored between the time of closing down and opening up of each transmission.

The introduction of equipment of this nature will immediately introduce uncertainties into the mind of anyone who has had dealings with automatic instrumentation, even of the most modest kind. The consternation that would be caused, for example, by the premature burning out of a radio valve (not, a rare source of trouble in electronic equipment) can be imagined, and to the authority responsible for the satellite vehicle, the manufacturer's six months' guarantee will be small consolation.

Nevertheless, it is remarkable to what extent automatic radio devices have been developed, as may be judged from the multiple-channel telemetering systems used in the American high-altitude research programme. One final illustration, however, may be given. A self-contained automatic weather station, which transmits weather data by radio, has recently been developed by the United States Bureau of Standards. The device, designed in the shape of a bomb, can be parachuted from aircraft on to inaccessible territory. The impact of landing sets off a small explosive charge which disengages the parachute and prevents the station being pulled along the ground. Either immediately or following a pre-set dormancy period, another explosive charge causes the station to rise into an upright operating position by means of six spring loaded legs. A third explosive charge extends a telescopic vertical antenna to a height of 20 feet. These actions are controlled by an electric clock. The station is then ready for automatic transmission at intervals predetermined by the built-in timing mechanism. The development model has an output of the order of five watts and operating on a frequency in the neighbourhood of five megacycles, it has performed reliably over land ranges of more than 100 miles (160 km.). The dry batteries used provided power for transmission of weather reports at three-hour intervals for more than 15 days.

These are some of the problems and prospects involved in the development of Minimum Satellite Rockets of a kind which are already being considered by the United States Military Establishment in the Earth Satellite Vehicle Programme.

* *This, of course, will depend on the nature of the "Satellite."*

ESTABLISHING CONTACT BETWEEN ORBITING VEHICLES

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(*Fellow, British Interplanetary Society*)

On consideration of the problem of bringing two orbiting objects together it is immediately apparent that the degree of precision required depends to a considerable extent upon the purpose for which contact is sought.

If, for instance, it is intended merely to destroy an object already established in an orbit by another missile discharged subsequently, the problem resolves itself into a simple matter of "homing" on the target body, and it is comparatively unimportant what the final rate of closing may be, or from which direction the final approach is made. With the use of proximity fuses it is not even necessary to effect contact at all.

This, then, is the most simple form of the problem and is mentioned, not because of its astronautical implications, but because of its military possibilities. It is, most probably, the first form that this operation will take.

A second example of the condition where contact may be sought is where it is intended to transfer fuel from one orbiting vehicle to another. A final rate of closing of a few feet per hour would be acceptable if the fuel transfer is to take place through a flexible pipe. The distance within which the vehicles must remain during the period of transfer is obviously determined by the length of the pipe, and as this is directly proportional to its weight, it must be as short as possible. There is the problem of how to secure the pipe to the "tanker" and this will require some ingenuity if it is to be accomplished automatically, without the assistance of an operator at the receiving end. One can imagine a small guided missile which is launched from the seeking vehicle carrying a hose towards some specially designated part of the target vehicle, which may take the form of a funnel into which it enters, actuating some automatic device which engages with the end of the hose and secures an airtight seal.

It will be necessary to ensure that the point of connection is to the "wet" end of the tank, as under conditions of passive flight, the lack of gravitational differential will permit the fuel to coalesce into a "blob" in the centre of the tank, which would defy any attempts to extricate it. If the tank is revolved, and a gas pressure applied at the central axis there should be sufficient head available, if take-off is from some annular space at the periphery, to overcome the friction of the pipe and the inertia of the fluid. Centrifugal pumps would not be good as they could be airlocked, and gas pressuring would probably prove the lightest and most compact method. Obviously it would be an advantage if the two vessels could maintain station while the transfer is in process, and there might be some directions of approach from which the relative attitudes of the two craft made the operation of fuel transfer difficult.

If it is found possible for members of the crew to move about freely in space

A paper read to the Second International Congress on Astronautics in London, September 7, 1951.

things would be simplified considerably. It would be necessary to provide suitable pressure suits, a gas-jet pistol, and a life line to enable the astronaut to be hauled back, or haul himself back if necessity arose. Until we know more about the effect of comparatively long periods of exposure to "gravitationless" conditions it is impossible to predict the degree of muscular co-ordination of which the operator would be capable. If it is found that some treatment is effective and the crew can, with experience, move about freely in space, it will make possible the erection of more complex structures from prefabricated parts independently projected.

This brings us to the requirements of the most difficult assignment of all, where parts are intended to be mechanically linked together. This demands that the final rate of closing shall be zero, to avoid damage by impact. It is also probable that the various components must be presented to one another in predetermined attitudes, and although it is true that the objects in orbital flight will have no weight in the sense of being attracted towards the centre of the Earth, as they would at its surface, they still have inertia. This will take some getting used to, and it would be dreadfully easy to get "nipped" between two massive parts moving deceptively slowly, or to attempt to fit a bolt through two parts not completely at rest relative to each other. It seems that it would be necessary to lash together parts which have to be mechanically linked during the process of assembly. It is difficult to see how this could be done unless the erecting crew can move freely about to do it.

Apart from these practical problems which arise when contact has been established, there are more general problems which apply to any form of contact. In the first place it will be necessary to define with sufficient accuracy the position, velocity, and direction of motion of the target body at some given moment, so as to be able to predict its position, etc., after a lapsed interval.

Let us assume that the orbiting body is established in an orbit at an adequate altitude to ensure that it is sufficiently clear of the atmosphere to prevent air-drag from reducing velocity to the point where the orbit is unstable. At first, no doubt, it will be desirable to make the altitude one which can be reached with the minimum energy, so it will only be sufficiently high to allow for the degree of divergence from a truly circular orbit which would result from inaccuracy in the direction or velocity at the commencement of passive flight. A probable order of altitude is about 500 kms. At this height, radar should be capable of providing an adequate trace of an orbiting rocket. When final momentum flight is established and the object is allowed to move freely under the combined effects of momentum and gravitation, it is constrained to follow certain well established conditions of motion, which dictate that it must pass through the point at which passive flight commenced at the completion of each circuit of the orbit, except to the extent that it has been affected by other gravitating bodies. At the distance postulated, the period of the orbit will be so short that many circuits would be completed before any considerable discrepancy arose, if the plane of the orbit lies in the plane of the Earth's rotation.

Knowing the intended orbit, it should prove fairly easy to check the

discrepancies between the orbit attained and that intended. This being done it is possible to predict the position of the orbiting object with great accuracy. A seeking rocket, equipped with radar homing should experience no difficulty in closing with its target from the position in which it would lie as the result of the inaccuracies of projection.

According to the nature of the homing device used there may be some difference in the final direction of approach. It should be a self-evident statement that the final rate of closing cannot be zero, but must be as little as possible to avoid the possibility of damage by impact. It is also inherent in any system of automatic homing that the correcting impulse must await the accumulation of sufficient error, and for this reason there must be some degree of hunting. Only where human intelligence is employed to anticipate error, can this effect be overcome. One therefore has to face the fact that the final relative attitude of approach is unpredictable.

It may well be that by the time this project is put into effect, the advance in television techniques will have been such that it will be possible to install equipment which produces the effect of a ground-based operator being present in the missile, directing it. If this should prove to be so then it will most probably be the best method of control.

Whatever the method employed to obtain the desired change of motion of the seeking vehicle, the final correcting movements, being carried out *in vacuo*, can only take the form of a series of impulses by which a new component of motion is superimposed on that already existing. This being so, the same direct facility of manoeuvre as applies in the case of aerodynamic steering cannot be attained; there will be some yaw in the turn, and it will be necessary to point the missile in quite a different direction to that in which it is desired to proceed, so the seeking vehicle is unlikely to approach its target head on. The actual technique of controlled motion *in vacuo* is as yet in its infancy and it is difficult to predict the degree of accuracy it may prove possible to attain. There will be a complete absence of external damping forces, so that rotation in any plane, once established, will continue until some force is exerted to annul it. Flywheel steering may prove advantageous, as it may prove impossible to arrange for torque jets to provide a line of thrust reaction in a plane passing through the centre of gravity as a result of which the torque force will also produce some displacement, either laterally or axially. It may well be that considerable experience will need to be acquired in handling craft *in vacuo* before sufficient precision is attained to make close manoeuvring possible.

Even during the process of fuel and personnel transfer the longitudinal and lateral stability will be inherently zero. Movement of any part of the combined mass must dictate a compensating movement of some other part to conserve momentum. The expulsion of fuel for instance, its friction against the walls of the pipe-line, and the adjustment of pressure distribution, will all produce compensating reactions which, although small, are significant because of the complete absence of exterior forces. Any force exerted which does not act directly through the centre of mass of an aggregate will produce a couple around the centre of gravity, because of the effect of inertia. This effect will be rather similar to conditions encountered when transhipping between small

boats except that, fortunately, the disturbing effect of wind and wave is absent.

Although it is true that a workman engaged on the erection of a "space-station" *in vacuo* could "put down" his tools anywhere in the space around him he would be foolish to make a practice of doing so if he was likely to need them subsequently. They would probably drift gently away, while his attention was engaged elsewhere, to become effectively lost against the bewildering background of the stars.

There are some current misconceptions relating to the degree of freedom enjoyed by objects in an orbit. Although it is true to say that there will appear to be no gravity due to the fact that all objects sharing a common orbital velocity have no tendency to fall directly towards the gravitating centre, as they would at the surface of the Earth, it is not correct to assume that conditions would be the same as would apply in true "gravitationless" space far from any gravitational centre, unless the orbit is so remote from the Earth's centre that the orbital period is considerable.

Consider the case where a vehicle is travelling in a circular orbit, radius 6,900 Kms., with a velocity of 7·62 Km./s. Let a body be projected with a velocity of separation of 10 m./sec. in a direction at right angles with the plane of the orbit. The object will now proceed in an elliptical orbit, commencing with a velocity of $\sqrt{7.62^2 + \cdot 01^2}$ Kms./sec., in a plane inclined to the original orbit at an angle $\tan^{-1}$ Va/Vo, where Va is the additional component, and Vo the original velocity. All closed orbits in a gravitational field must describe an ellipse, one focus of which is at the gravitational centre, therefore the two orbital planes must intersect along a line produced from the point of departure through the focus at the gravitational centre, to a second point on the further side of the ellipse.[1] This means that the maximum separation will occur at apogee, after which the two bodies will begin to approach each other again. In the case given, the maximum separation will be approximately 10 Kms.

It is rather surprising to find that if the new velocity had been added tangentially, or subtracted, or added or subtracted radially the maximum displacement is still about the same order, that is $\pm$ 9 kms.

This gives us some idea of the degree of dispersal which would result from an error of this magnitude, and if one considers that this is the equivalent of a mistiming of projection by a little more than a second, the problem of subsequently projecting a radar equipped automatically homing missile to within range of a target object is not going to demand impractical standards of accuracy. Far greater distances would still be within radar range.

It has been shown in previous publications,[2,4] that considerable advantage would accrue if it proved possible to refuel in an orbit. It has also been stated that it would be an advantage from the design point of view, if it could be arranged for one type of vehicle to ferry passengers from the surface to an orbit, another to transport them to their destination landing and return to the orbit, where they would tranship back to the ferry and glide to Earth. The transport vehicle would remain in the orbit, to be refuelled again from tankers. This scheme has the merit that fuel expended on lifting the structure of the transport vessel is saved if the trip is repeated. This seems to be basically

sound if, and only if, it proves possible to transfer fuel and personnel from one orbiting vehicle to another.

Whatever the case for Satellite Stations[2] may be, it appears that the suggestion that they should be constructed as an aid to this operation of transhipment is the least telling.[3] If it is possible for members of the crew to move about freely in space, then they do not need a space-station to make transhipment possible. If they can arrange the transfer of fuel by pipeline, there is no reason for introducing a quite purposeless mass of metal in the form of a space-station, which would require the expenditure of sufficient fuel to give orbital velocity to a structure of perhaps a thousand tons or so, when it could be dispensed with entirely. After all, the cabin of the transport rocket has to be equipped for sufficient period to cover the voyage out, the stay, and the return to the orbit, so the comparatively short period during which the refuelling and transhipment is proceeding needs, in my view, no special measures. If, for other reasons it is decided, when space flight is sufficiently developed, to erect such a station as Ross and I have described,[4] this could be left until some part of its total mass could be projected from the moon, and be composed of components fabricated there from indigenous materials.

Such a proposal may come comparatively late in the development of Astronautics; after the Moon has been colonised in fact. I have tried to show that the fabrication *in situ*, of complex aggregates involves greater accuracy of control of the components than would be called for to tranship the fuel or personnel in the open. The idea of "docking" a spaceship inside, or on, or even alongside a space-station is suicidal lunacy, inviting disaster for no good reason at all. It simply represents one more landing, and one more take-off from an airless body than is necessary.

When the military advantages of such stations are advanced, their extreme vulnerability is ignored. They could not be constructed, in the first place, unless guided missiles were sufficiently developed to deliver the material to the orbit accurately,[5] and to such missiles shooting down a passive orbiting body would be child's play.

It would be very much better for Astronautics if its adherents refrain from making false claims, and concentrate on advancing the legitimate claim that it is a branch of science which offers unexampled opportunities of acquiring new knowledge of the Universe around us, thus advancing the mastery of man over his environment. We should seek to secure financial allocations on the National and International scale for the advancement of this infant science in its own right, so that those who wish to work for the betterment of man are freed of the necessity to labour at tasks repugnant to their philosophy in the hope that information will come to light which will be applicable to the problems of space-flight.

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(1) *Ballistics of the Future* (Kooy & Uytenbogaart).
(2) *Interplanetary Flight* (A. C. Clarke).
(3) *The Conquest of Space* (Ley & Bonestell).
(4) *Orbital Bases* (H. E. Ross), *J.B.I.S.*, **8**, 1, 1–19, 1949.
(5) *Guided Missiles* (A. R. Weyl).

LANDING OF SPACE-CRAFT

By Edmund V. Sawyer
(Pacific Rocket Society)

Summary*

During the approach to a planet, any spaceship will have a large velocity excess which must be removed before a landing can be made. This velocity is due to the gravitational attraction of the planet, the orbital motion of the ship, and the rotation of the planet on its axis. It may amount to several miles a second.

The most frequently proposed method of landing involves the use of aerodynamic drag in a series of "braking ellipses." This will require very skilful navigation and must be regarded as a hazardous manoeuvre. It is suggested that it would be better to use propellant for braking to sub-orbital velocity, followed by aerodynamic drag to the required landing speed.

The most efficient braking device is the parachute drag brake (also known as "drogue chute" or "parabrake"). It is controlled by a drag cord passing through rings on the skirt of the canopy so that the drag force can be varied.

One of the essential requirements of a parabrake is stability, which rules out the common flat circular design. Mushroom-shaped and ribbon parachutes have better characteristics. A new type of parabrake rotates rapidly in operation and gives greater control and stability.

A parabrake for space-craft deceleration would have an automatic load-governed reefing control to maintain a constant drag force. Parabrakes of different sizes would be used during the descent. Nylon is a preferred material, but loses its strength at about 300° F. Precautions must also be taken against low temperatures on long flights as a frozen parabrake would be shattered when ejected.

The parachute is, on a weight basis, the most economical device for lowering a heavy load at a moderate velocity. Multiple clusters are preferable to single large canopies, as parachutes over 70 feet in diameter are difficult to handle.

For standard sea-level conditions, a 60 ft. diameter parachute is required for each 5,000 pounds of load if the rate of descent is not to exceed 50 ft./sec. Such a parachute would weigh about 68 lbs. and occupy 3 cu. ft. Rates of descent of less than 20–25 ft./sec. demand impracticably large parachutes, and it appears necessary that in many cases the landing impact must be softened by a short burst of rocket braking.

At this point stability would be critical, and there is the additional hazard of reflected blast. The parachute cluster may have to be cut loose during the last few feet of descent.

Since the landing area may be irregular, it will be necessary to provide a shock-absorber array of wide tread with long travel, and some form of self-levelling control would be essential.

It is concluded that the most economical landing technique would involve

* *This and the following are summaries of other papers presented at the Congress.*

rocket braking into a tight orbit, drag by flaps and parabrakes to a velocity of about Mach 0·5, stern-first descent with a parachute cluster at 40–60 ft./sec., a short rocket burst for final retardation, and touch-down on wide-tread shock-absorbers.

BIOLOGICAL PROBLEMS OF THE EARTH SATELLITE VEHICLE

By Medecin-General P. Bergeret*
(G.A.F., France)

Summary

The problem of life in interplanetary flight or on an artificial satellite is an extension of the problem of life in high altitude flight. The provision of a breathable atmosphere and maintenance of a tolerable temperature is the same in both cases and no trouble should arise.

One of the major unknowns is the effect of zero-g or "free fall" conditions on the human body during a prolonged period. This condition is impossible to simulate on the ground but investigations should be possible with some of the present-day high-altitude jet-propelled aircraft. With these, zero-g conditions may be realised for 10 sec. and half-g for 35 sec. It seems as though interplanetary rockets and space stations must have artificial gravity and this may best be achieved by rotating the vehicle. Sufficient information exists on the effect of acceleration on the body to say that no danger exists either at take-off or landing.

Another important problem is the effect of all the radiations normally stopped by the Earth's atmosphere but no doubt a suitable screen could be found.

THE OPTIMUM SATELLITE FREIGHT ROCKET

By Ing. H. Hoeppner
(G.f.W., Germany)

Summary

A four-step rocket is described capable of carrying a freight load of 3·5 tonnes into an orbit at an altitude of 1,669 Km. The time for one complete circuit of the Earth in this orbit is two hours. The rocket propellants used are nitric acid and hydrazine for all stages. These are assumed to give a specific thrust of about 300 Kg./Kg./sec. *in vacuo*. A combustion chamber pressure of 100 atmospheres is used for the first two stages and 50 atmospheres for the last two. The first two steps have a net weight of 110 tonnes and 33 tonnes each respectively and are intended to be recovered by parachute, the third step, discarded and the last step is intended to be left in the orbit. The

*Read by M. Jean Gallavardin,

all-up weight of the complete project is 871 tonnes and its overall length 35 metres, the maximum diameter being 11 metres. The first step has a thrust of 1,800 tonnes for a burning time of 77 secs. The pump power requirement is 105,000 H.P. The total burning time of the four steps is 844 sec., during which time about 710 tonnes of propellant is burnt. The last stage has a thrust of 5 tonnes for a period of 555 secs. A version of the last stage is fitted with wings of span 20 metres and is intended for transportation of human loads of 0·92 tonnes. This version can be glided back to a landing on Earth. All steps carry a small propellant reserve. A summary of the relevant data is given in the table.

		I	II	III	IV
Tonnes	Payload	234	66·1	18·4	3·5
	Empty weight	110	33·0	8·65	5·5
	Propellant weight ..	527	134·9	39·05	9·5
	All-up weight	871	234	66·1	18·4
	Thrust	1,800	400	100	5

START, RETURN AND LANDING OF AN OPTIMUM SATELLITE STEP ROCKET

By Dipl. Ing. H. Kuhme
(G.f.W., Germany)

Summary

The aerodynamics of such a rocket are considered; at various times during its operation, flight in four different regimes is necessary, viz.:—

(i) Subsonic, Mach No. < 1.
(ii) Transonic, Mach No. $= 1$ to 3.
(iii) Supersonic, Mach No. up to 20.
(iv) Condition encountered at heights of about 100 km. where mean free path of air molecules is large compared with linear dimensions of rocket. In practice, the flight Mach No. will simultaneously be high. (20 or above).

Different laws of flow apply for all four of these regimes, which complicates the aerodynamic design.

For (i), the drag is largely determined by the body fineness ratio and smoothness; as (ii) is entered, there is a sharp rise in drag coefficient (up to 10 x the low-speed value), and accurate lift calculations can be made by the Ackeret-Busemann method. Bodies with ogival nose shape and thin wedge-shaped aerofoils are best. Swept-back wings are advantageous between $M = 0·8$ and 1·2, but the rocket will not operate long in this region. Straight wings would therefore probably be used, unless the landing glide dictates otherwise, which is doubtful.

In (iii), Newton's laws, derived from the collision of particles with an

inelastic body, govern the lift and drag. Flat-plate aerofoils are theoretically best, though for constructional reasons wedge-sections should again be used; aerodynamically, this regime is not far removed from (ii).

In (iv), drag coefficients rise again, but the dynamic pressure will be negligible in practice, hence the aerodynamic forces will be so very small that they are even considered useless for initial braking prior to landing.

Below 50 km., however, lift/drag ratios of 6 to 8 are considered attainable for landing manoeuvres using aerodynamic braking. It is thought that fears of excessive aerodynamic heating are groundless.

During take-off, the maximum total resistance will occur at a height of 8 to 10 km., where the flight Mach No. is about 1·5.

THE FOUNDATION OF THE SPACE-STATION

By Ing. G. von Pirquet
(O.G.f.W., Austria)

Summary

The first step towards the establishment of a space-station would be the "long-distance rocket" which would have a maximum range of about one-half the Earth's circumference. Much of this distance would have to be used for braking as would also be the case with transport rockets to and from a space-station. The maximum speed of these long-range rockets would be 6–7 km./sec. and considerable problems would arise from aerodynamic heating.

After this, orbital rockets would be built for practising manoeuvring, refuelling in space, etc. The final step would be orbital transport rockets and the construction of the space-station. In the first instance the hulls of a number of the transport rockets could be used as a skeleton.

The space-station would have a number of uses—as an astronomical observatory, for astrophysical spectro-analysis, for radio and television transmission and weather observation. Astronautically speaking it would be of inestimable value for refuelling space-ships.

OPTIMUM ORBIT OF A SPACE STATION FOR RADAR TRACKING

By Dr. R. Merten
(G.f.W., Germany)

Summary

A method for the measurement of the position of an orbital rocket both during its ascent and throughout its orbit is described. A ground transmitter and three receivers are used and these can be used either for radar tracking or positioning by a doppler method. The author favours the latter as giving the greater accuracy. Wavelengths of 10 cm. to 1 metre are recommended. For observing an orbital rocket from one set of ground stations an elliptical orbit is suggested. The viewing time would depend on the ellipticity of the orbit.

DESIGN PROBLEMS OF THE SPACE-STATION

By H. H. Koelle (G.f.W., Germany)

Summary

The paper defined the space-station and discussed the tasks it will have to fulfill during all stages of its development. A general equation for calculating construction and maintenance costs is derived.

The most favourable shape and layout of the space-station is then considered, and an example is derived which is shown to be closely connected with the design of the "Optimum Satellite Cargo Vehicle" described in Mr. Hoeppner's paper.

The overall costs of this proposed design are then calculated and the possibility of reducing them considered. They are compared with the income which such a station might earn.

In particular it is shown that the design of the cargo rocket and the space-station must be considered together to obtain the most economical solution.

PROPOSAL FOR THE CONSTRUCTION OF A SPACE-STATION

By Ing. A. Püllenberg (N.W.G.f.W., Germany)

Summary

A two-step rocket is proposed with expendable tanks in the first step. In this type of construction the tanks are cast off as used and thereby a good mass ratio is obtained. The second step uses the same propulsion equipment as the first step and is used as the basis for the space-station. Supply rockets are used to complete the structure of the station.

The use of a collapsible balloon-like structure is suggested which could be inflated in space and sprayed with a plastic material to form cell-units for the station.

THE SPACE-STATION AS AN ASTRONOMICAL OBSERVATORY SITE

By A. L. Joquel II (Reaction Research Society)

Summary

In this short paper (read by Mr. E. V. Sawyer) the advantages of the space-station for astronomical observations are pointed out.

HOW WILL THE SPACE-STATION BE CONSTRUCTED?

By Ing. R. Nebel (Germany)

In this further short paper the author reviews his early work at the Raketenflugplatz and indicates that his views on the design of a space-station have not changed materially since they were originally propounded in 1932. It would not be practicable for a space-station to be set up, however, until atomic energy can be harnessed to rocket propulsion.

Annual Report

of the

British Interplanetary Society

(Limited by Guarantee)

SIXTH ANNUAL GENERAL MEETING

NOTICE IS HEREBY GIVEN that the SIXTH ANNUAL GENERAL MEETING of the BRITISH INTERPLANETARY SOCIETY will be held in the Kent Room, Caxton Hall, Caxton Street, London, S.W.1, on **Saturday, the 8th day of December, 1951,** at **6** o'clock in the evening precisely, for the transaction of the business specified in the Agenda below.

AGENDA

1. To hear the Chairman's speech.
2. To receive the annual statement of accounts and balance sheet and the auditor's report thereon.
3. To grant authority to the Council to borrow money up to a maximum to be fixed by the meeting for the purpose of establishing office accommodation for the Society.
4. To elect four Members of the Council of the Society. In accordance with the provisions of Article 15, the following existing Members of the Council will retire at that meeting and, with the exception of Mr. Cleator, offer themselves for re-election:

   P. E. Cleator. H. E. Ross.
   J. Humphries. Dr. L. R. Shepherd.

   The following additional names have also been nominated:—

   A. E. Dixon *Member.*
   C. H. Gibbs-Smith *Member.*
   W. N. Neat *Fellow.*

   Since the number of nominations exceeds the number of vacancies, election will be by postal ballot. The necessary ballot papers are enclosed with this agenda.
5. General discussion of the affairs of the Society during the past year. Members are invited to submit any suggestions or questions they have in mind, to which the Chairman and Secretary will reply as necessary.
6. Any other business.

By order of the Council,

L. J. CARTER,

Secretary.

A member who cannot be personally present at the meeting may appoint by proxy some other person (who must be a member of the Society) to attend and vote on his behalf, subject, however, to the limitation that a proxy cannot vote except on a poll.

ADDRESSES DELIVERED TO THE LONDON MEETINGS OF THE SOCIETY DURING THE SESSION 1950-1951

Saturday, 7th October, 1950

The session opened with a "Report on the First Astronautical Congress, Paris, 1950." This was a meeting at which the B.I.S. delegates to the Paris Congress, on 30th September-2nd October, 1950, gave their impressions of the proceedings and discussed the results obtained.

88 members and visitors were present.

Saturday, 4th November, 1950

Two papers were delivered:—

(*a*) *The Earth's Atmosphere*, by J. Humphries, B.Sc., A.M.I.Mech.E., A.F.R.Ae.S., and

(*b*) *Problems of Missiles Entering the Atmosphere*, by T. R. F. Nonweiler, B.Sc.

Both papers were printed in the *Journal*, Vol. 10, No. 1, January, 1951.

119 members and visitors were present.

Saturday, 2nd December, 1950

The Lunar Base, by G. V. E. Thompson, B.Sc., A.R.C.S., A.R.I.C.

The advantages and purpose of such a base and the problem of maintaining it from lunar resources, were discussed.

The paper was printed in the *Journal*, Vol. 10, No. 2, March, 1951.

138 members and visitors were present.

Saturday, 6th January, 1951

"A Symposium on the Orbital Rocket" was presented, comprising the following three papers:—

(*a*) *Some Preliminary Considerations*, by K. W. Gatland.

(*b*) *The Rocket Structure, with special reference to Expendable Construction*, by A. E. Dixon.

(*c*) *Conception of an Instrument-carrying Rocket*, by A. M. Kunesch.

These papers were printed in the *Journal*, Vol. 10, No. 3, May, 1951.

102 members and visitors were present.

Saturday, 3rd February, 1951

Some Interplanetary Orbits, by Arthur C. Clarke, B.Sc., F.R.A.S.

This was a substitute, at short notice, for the advertised talk "Interplanetary Orbits," cancelled owing to the illness of the speaker, Dr. J. G. Porter.

104 members and visitors were present.

Saturday, 3rd March, 1951

Combustion in the Rocket Motor, by Professor A. D. Baxter, M.Eng., M.I.Mech.E., F.R.Ae.S.

This paper discussed the history of a droplet of fuel during its passage from injector to exhaust in a liquid-propellant motor. It was printed in the *Journal*, Vol. 10, No. 3, May, 1951.

94 members and visitors were present.

Saturday, 24th March, 1951

"Film Show." In view of the great interest shown in the meeting, it was decided that two performances be held on the same day at the Science Museum, South Kensington, S.W.7 (by kind permission of the Director).

The films shown were as follows:—

(*a*) Rocket Instrumentation.

(*b*) The Story of Palomar.

(*c*) The German A4 Rocket.

(*d*) A German film on the effects of increased "*g*."

130 members and visitors were present for the first performance, and 118 for the second.

Saturday, 7th April, 1951

Biological Problems of Space Flight, by Professor J. B. S. Haldane, F.R.S.

This paper was given in place of Professor J. D. Bernal's "The Evolution of Life in the Universe," owing to the absence of Professor Bernal from England. It discussed how men would live in the spaceship and on other planets, and what sort of life might be encountered outside the Earth. A summary of the paper was published in the *Journal*, Vol. 10, No. 4, July, 1951.

Some 2–300 members and visitors were present.

SYLLABUS OF ACTIVITIES OF THE NORTH-WESTERN BRANCH DURING THE SESSION 1950-51

Saturday, 23rd September, 1950

"The First Moon Rocket," by Eric Burgess, F.R.A.S. Imaginary impressions of the experiences of the first space-travellers, how they will be clothed and fed, the types of things they will see and do, what they may expect to experience when on the Moon.

65 members and visitors were present.

Saturday, 21st October, 1950

"The Interplanetary Project," by A. V. Cleaver, A.F.R.Ae.S. Aspects of

interplanetary travel, difficulties in current research, probable future lines of development, scale, cost, economic and political effects, finance and organisation.

A short film with sound track made by the N.W. Branch of the Paris Congress was also shown.

33 members and visitors were present.

Saturday, 25th November, 1950

"The Galaxy," by J. C. Farrer, F.R.A.S. An outline of modern theories regarding the origin and constituents of the galactic system and the place of our own solar system in relation thereto.

38 members and visitors were present.

Friday, 15th December, 1950

Visit to the Godlee Observatory, College of Technology, Manchester. Conditions were excellent and members were able to observe the stars and the planet Jupiter.

20 members were present.

Saturday, 20th January, 1951

"The Challenge of the Spaceship," by A. C. Clarke, B.Sc. An attempt to develop a philosophy of astronautics covering a large field, with emphasis on the philosophical, moral and social side of the problem of interplanetary flight and its impact upon human society.

96 members and visitors were present.

Saturday, 17th February, 1951

"The Design of Rocket Motors," by J. Humphries, B.Sc., A.F.R.Ae.S., A.M.I.Mech.E. An outline of the methods employed in the design of liquid propellant rocket motors, including choice of propellants, choice of propellant expulsion systems, combustion chamber design and method of testing.

51 members and visitors were present.

Saturday, 31st March, 1951

Annual Film Show which included the screening of the following films:—

(*a*) Wonder Jet.
(*b*) Uranium Fission.
(*c*) Faster Than Sound.
(*d*) High Altitude Research.
(*e*) The Story of Palomar.

260 members and visitors were present.

Saturday, 21st April, 1951

"The Planet Mars," by H. L. Dilks, F.R.A.S. A review of the physical conditions of the planet and the various theories regarding its evolution and what might be encountered there by travellers from earth.

66 members and visitors were present.

Saturday, 19th May, 1951

A general meeting of the North-Western Branch membership was held to discuss Branch policy and to elect a local Branch Council to manage the affairs of the Branch.

34 members were present.

Saturday, 21st July, 1951

A visit to the Godlee Observatory where members were able to observe a projected image of the sun, to examine the instruments carefully and to see the planet Venus.

15 members were present.

Saturday, 15th September, 1951

"Rocket Tests in the Mojave Desert," by Edmund V. Sawyer. The North-Western Branch was pleased to hear an address by a prominent and active member of the Pacific Rocket Society on the work of that society and the difficulties encountered in practical tests of small experimental rockets. Several films were shown by Mr. Sawyer on the work of this Society.

92 members and visitors were present.

Saturday, 22nd September, 1951

"Modern Sounding Rockets," by Eric Burgess, F.R.A.S. A survey of the work and instrumentation of modern high altitude rockets such as the V-2 Aerobee and the Viking with details of the experimental techniques involved and the results obtained.

47 members and visitors were present.

SYLLABUS OF ACTIVITIES OF THE MIDLANDS BRANCH DURING THE SESSION 1950-51

Saturday, 17th March, 1951

"Film Show." The opening meeting consisted of two performances of the following programme of films:—

(*a*) The German A4 Rocket.
(*b*) The Johns Hopkins University High Altitude Research Programme.
(*c*) Pictorial Survey of the Missile Programme of the Johns Hopkins University, Applied Physics Laboratory.
(*d*) The Story of Palomar.

150 members and visitors were present for the first performance and 170 for the second show.

Saturday, 21st April, 1951

"Rockets and Space Travel," by J. Humphries, B.Sc., A.F.R.Ae.S., A.M.I.Mech.E. A survey of liquid propellant rocket motors; their application to space flight and a review of the problems involved in its realisation.

90 members and visitors were present.

SIXTH ANNUAL GENERAL MEETING

(For the convenience of members unable to be present, the Chairman's Address is reproduced below.)

CHAIRMAN'S ADDRESS

GENTLEMEN,

It gives me great pleasure to present the report of the Council for the period 1st October, 1950 to 30th September, 1951, as this has undoubtedly been the most momentous and successful year in the Society's history. It will also be the last year on which the Society can continue to operate on a voluntary basis, for the load on our devoted Secretary, Mr. L. J. Carter, has now reached such proportions that the question of obtaining staff and an office is a matter of urgency. This is a point to which I shall return later.

Membership

Our membership at 30th September, 1951, totalled 1,491, comprising 6 Honorary Fellows, 356 Fellows and 1,129 Members. This represents an increase of no less than 566 during the year—a result all the more remarkable in view of the raised membership fees. It is instructive to give the figures for the last five years:—

Total membership at 30th September,	1947 = 444		
" " " " "	1948 = 502	Annual increase	= 13%
" " " " "	1949 = 577	" "	= 15%
" " " " "	1950 = 925	" "	= 60%
" " " " "	1951 = 1,491	" "	= 61%

Whether this rate of increase will continue remains to be seen: certainly it shows no sign of slackening at the present.

During the year, I regret to say, the Society lost two of its most distinguished members—Dr. Olaf Stapledon and Mr. George Bernard Shaw.

Publications

The Society has during the past year issued the following publications:—

(*a*) Six *Journals*: Vol. 9, No. 6 (November, 1950) and Vol. 10, Nos. 1–5 (January, March, May, July and September, 1951).

(*b*) The Annual Report and List of Members for 1950 in October of that year.

(*c*) A fifth and sixth printing of the Book List, which is in great demand and requires revision at ever more frequent intervals owing to the increasing number of books on rockets and astronautics.

In addition, Fellows of the Society have received the *Journal* of the American Rocket Society: Nos. 82, 83, 84 and 85.

The *Journal* of the Pacific Rocket Society has now been suspended: the A.R.S. *Journal* has now been greatly enlarged and from the September, 1951, issue is appearing bi-monthly in a larger format.

It has been decided not to issue a List of Members for 1951. This is partly as a measure of economy, but is in any case forced upon us at the moment as it is impossible to undertake the very great labour of preparing a list of some 1,500 names and addresses. We hope that it may be possible to do this in 1952.

We have again increased the number of copies of the *Journal* printed, but even the present figure of 2,500 is not sufficient to cover all the enquiries we receive and each issue is exhausted within a few months.

The Abstracting service, run by Mr. J. Humphries, has been extended and improved. All abstracts are now classified, numbered and indexed.

All material submitted to the *Journal* is examined by the Publications Committee, which consists of Dr. Shepherd, Messrs. Carter, Cleaver and myself.

A minor, but very successful, publication during the year was the "Destination Moon" Christmas Card, which sold in large quantities and also acted as a very effective advertisement for the B.I.S. The same may be said of the set of six postcards issued in connexion with the Congress. We hope that a Society Christmas Card may be a regular feature, but this year the heavy pressure of more essential work has ruled one out.

I would like to take the opportunity here of expressing our thanks to our Printers, Messrs. Heffers, for their continued co-operation and the high standard of work they have produced for us.

Lectures and Meetings

As recorded elsewhere in this issue, the Society held eight general meetings in London in the period under review, besides the normal Annual General Meeting in December, 1950, and an Extraordinary General Meeting on 26th May, 1951, a further twelve in Manchester under the auspices of the North-Western Branch, and two in Birmingham. Attendance continues to be gratifyingly high: indeed, at two meetings it was impossible to accommodate all those who came. The Council receives an increasing number of requests for lecturers from organisations of all types—scientific, educational and social. As the number of speakers is, despite some recruits, still limited, it has not been possible to accept all these requests and priority has had to be given to the scientific bodies. Any members who are willing to give talks are reminded that lecture notes and lantern slides are available.

Among the many outside talks given by members of the Society mention should be made of a series by Mr. A. V. Cleaver and other Members of the Council, to branches of the Royal Aeronautical Society—a series which seems likely to continue indefinitely! An interesting sign of the times was a request from the Institute of Navigation for a speaker in a symposium on the problems of interplanetary navigation, held at the Headquarters of the Royal Geographical Society on 21st April, 1950. The astronomical speaker was Dr. R. d'E. Atkinson, Chief Assistant of the Royal Observatory, and the Chairman was Sir Robert Watson-Watt. We may expect more of such joint meetings with other societies in the future.

The year's most important event—the Second International Congress on Astronautics—is reported elsewhere, so I need only mention it here.

Film shows were arranged during the year in London, Manchester and Birmingham, and these continue to be very popular. On 17th March, 1951, we arranged a programme at the Central Technical College, Birmingham, to discover the extent of local interest in astronautics. I am glad to say that attendance was so good that two performances had to be given, and thus encouraged we have launched a Midlands Branch.

Library and Information Service

The lending library has now some 70 books on rockets, astronautics and astronomy available on loan to Fellows and includes practically all the major works on astronautics.

The Information Service (which is also run by Mr. J. Humphries, 97, Churchill Avenue, Southcourt, Aylesbury, Bucks.) is open to use by all Members and now contains some 500 articles and reports and 150 Journals of the various rocket societies, including an almost complete file of our own publications. Many of the items mentioned in the "Abstracts" are added to the Information Service from time to time and Mr. Humphries is always willing to locate articles on any particular topic.

During the forthcoming year we hope to make a further increase in the number of books available on loan, and also to start small local libraries for the North-Western and Midlands Branches. Further details will be announced in the *Journal* as soon as the necessary arrangements can be made.

The Library Committee continues to consist of Messrs. Carter, Cleaver, Humphries, Thompson and myself.

Technical Advisory Committee

This has continued to meet under the Chairmanship of Dr. L. R. Shepherd and has held 5 meetings during the year, most of which were concerned with discussion of the papers to be delivered at the Congress.

Books, Radio, Television and Films

During the past year popular interest in astronautics has steadily increased, and this has been reflected in many fields. There have been innumerable articles in the press, most of them referring to the Society. In particular, the International Congress on Astronautics received extremely wide publicity, as described on page 330.

During the year the second George Pal film, *When Worlds Collide*, had its first screening in this country, and at the moment we await, with some apprehension, the threatened flood of space-travel films from Hollywood.

I would like to express here the gratitude of the B.I.S. to Mr. George Pal for a copy of "Destination Moon," which he has undertaken to present to the Society. This will be a much-valued acquisition and it is pleasant to know that this important film will be available in our archives, for screening on appropriate occasions. I would like to express the hope that this will be

done at the Society's Extraordinary Meeting—not, I hope, too far in the future —celebrating the first lunar landing!

The B.B.C. has been fairly active in the field of astronautics during the year. A half-hour programme "Focus on Interplanetary Flight," was broadcast on 12th January, 1951. The B.I.S. gave technical advice, and Mr. Cleaver spoke at the conclusion of the feature. During the Congress, Mr. K. W. Gatland and Lt.-Cdr. F. C. Durant, U.S.N., appeared in the programme "In Town Tonight," and there were various other short references in the various B.B.C. Overseas Services.

There were two TV programmes on the subject of space-travel:—*Rocket Flight* (9th October, 1950) and *Voyage to the Moon* (24th November, 1950), both given by your Chairman.

In the book world, the year opened auspiciously with the publication here of the mangificent Bonestell-Ley work, *The Conquest of Space*, which promptly became something of a best-seller and must have brought many into the astronautics fold. I presume that, for the record, I must mention that it ended with the publication of my own *The Exploration of Space*!

Exhibitions.

In connexion with the display "50 Years of Flight," organised by the *Daily Express* and the Royal Aero Club at Hendon, 19th–21st July, 1951, we were asked to plan an exhibition showing the history and future prospects of astronautics. This must have been seen by many thousands of visitors, and the *Daily Express* kindly arranged for its installation at the Caxton Hall on the last day of the September Congress. It is possible that this display may be maintained on a permanently available basis.

Branches

At Manchester, the North West Branch has continued to flourish as is shown by the record of its meetings.

In March, as I have mentioned, we commenced activities in Birmingham with a film show. This was followed by a lecture by Mr. J. Humphries on 21st April, 1951, and thanks to the encouraging response obtained at these meetings a Midlands Branch has been formed with Mr. N. R. Nicoll as Branch Chairman and Mr. A. C. Rotherham as Secretary. We wish this new branch every success in its activities and hope that our many members in the Midlands area will give it every support.

Accounts

The general financial position of the Society has shown a satisfactory improvement during the year, despite the heavy and non-recurrent expense of the Congress. There are two main reasons for this. The first is, of course, the steady rise in membership: the second is the increase in fees which took effect from 30th June, 1951. Without this increase the Society would not be in anything like so sound a position as it is today, nor would it be able to face the changes which, as I will explain in a moment, now lie before us.

I would like to express our thanks here to all those members who have generously made donations to the Society during the year. It is particularly gratifying to record that the amount donated shows a substantial increase over the previous year. A list of all those who made gifts of over 10/- appears on page 332.

I am also pleased to note an increase in the number of members compounding their subscriptions. This is not only a tacit vote of confidence in the Society, but it also gives us a much-needed capital reserve—which appears in the "Establishment Fund Deposit Account." The purpose of this fund is to make a provision for the time, now imminent, when the Society will have to obtain its own office accommodation, equipment and furniture.

May I again remind members that, by compounding their subscriptions, they may also save themselves a considerable amount of money in the long run? To encourage this step, we are keeping the existing scales in force until 31st December, 1951, despite the increase in membership fees. The rates are as follows:—

Age limits	Membership	Fellowship
	£	£
20-25	25	35
26-30	23	32
31-35	21	30
36-40	18	26
41-50	16	22
51-	14	18

These values will be increased as from 1st January, 1952, in proportion to the new membership fees, so all those wishing to avail themselves of this concession should do so before the end of the year.

Before leaving the Accounts, I would like to raise an important point which concerns the future rather than the period under review. Very soon the Society will have to acquire offices of some kind, and it is possible that this can be done most economically not by the renting of premises but by their purchase with the assistance of a mortgage. Though at the moment we have nothing definite in mind, we wish to explore this possibility and are therefore requesting the necessary authority. According to Article 23 of the Articles of Association: "The Council may, with the prior consent of a General Meeting, raise or borrow money for the purpose of doing anything that may be conducive to the attainment of the Society's objects." I propose to ask the meeting to grant this authority, which hitherto we have not required.

Council

During the past year your Council has met 11 times to conduct the Society's business. This has been far heavier than in any previous year, partly owing to the enormous amount of "staff-work" in connexion with the Congress.

Under Article 15 of the Articles of Association, four members of the current Council have retired, viz: Messrs. P. E. Cleator, K. W. Gatland, H. E. Ross and Dr. L. R. Shepherd. The last-named three have offered themselves for

re-election, but Mr. Cleator has not done so in view of the fact that his residence in Cheshire makes it impossible for him to play an active part in our deliberations. We are, of course, very sorry not to see the Founder of our Society on the new Council, and while expressing our gratitude to Mr. Cleator for his many past services, I feel sure that we can still count on his advice in future, even if he cannot attend our meetings as often as he would wish.

Besides their attendance at our meetings, the members of the Council have delivered numerous lectures, have taken on many of the odd jobs involved in running this Society, and have done their best to relieve Mr. Carter of as much secretarial work as possible. I would like to thank them all for their help during the year.

And now we come to our plans for the future. During the year, when I announced the need for increased subscription rates, I explained how the work of the Society had grown so greatly that it could no longer be handled on a voluntary, spare-time basis. Mr. Carter has performed prodigies of administration and has streamlined our records to the utmost, but the sheer clerical labour of running a society of 1,500 members is now so great that it is physically impossible for him to handle it all—and quite unfair to him and his family that he should be expected to do so. Anyone who has had no practical experience of running a society can have little idea of the work involved, even in the case of a much smaller organisation than ours. The out-going correspondence amounts to over 6,000 items a year: books have to be kept recording all expenses and income: minutes have to be written up in the manner required by law (since our Society is a Limited Company): lecture programmes have to be arranged: a card index of all members has to be kept up to date: the *Journal* has to be edited—now a major task in itself. These are only some of the jobs which, for various reasons, cannot be delegated and have to be done centrally. You will appreciate that the work involved in running this Society is now approximately that of administrating a small business—and it is still increasing rapidly.

It is, therefore, urgently necessary to obtain some full-time clerical assistance, and at least a modest headquarters where the Society's records can be kept. It would be ideal, of course, if we could have our office in the Central London area, but this will probably be out of the question for some time to come.

The General Purposes Committee (which consists of Mr. Carter, Mr. Cleaver and myself) is now exploring these possibilities, and I hope that we can report results in the very near future. The Society cannot expand or even continue at its present level unless we place its organisation on a businesslike footing. This is a crisis we are glad to meet, for it is a crisis brought about by the growth and success of the Society. Certainly when the B.I.S. was reconstituted only six years ago we scarcely expected to reach our present membership and status quite so quickly!

In conclusion, I would again like to thank all those who have made this progress possible, and to express my confidence that it will be maintained in the year that lies ahead.

ARTHUR C. CLARKE,
Chairman of the Council.

8th December, 1951.

The British Interplanetary Society

(Limited by Guarantee)

INCOME AND EXPENDITURE ACCOUNT for the year ended 30th September, 1951.

1950	EXPENDITURE.	£ s. d.	£ s. d.
£			
	To Management Expenses—		
145	Printing and Stationery ..	252 13 5	
136	Postage, Telegrams and Telephone	181 10 9	
8	Accountancy and Audit ..	10 10 0	
52	Publicity and Advertising ..	45 10 0	
21	Library Expenses	20 16 5	
6	Bank Charges and Loss on Exchange	11 7 7	
13	Clerical Assistance	23 14 7	
4	Travelling and Entertaining Expenses	5 11 3	
23	Sundry Expenses	16 12 11	
408			568 6 11
966	,, **Publications**		1,218 17 1
63	,, **Expenses of Meetings** ..		96 11 11
—	,, **International Congress Expenses** less receipts		271 17 9
	,, **Depreciation and Amounts written off—**		
16	Furniture and Equipment ..	46 0 0	
30	Library	46 15 6	
46			92 15 6
20	,, **Transfer to Subscription Reserve**		100 0 0
	,, **Excess of Income over Expenditure** for year carried to Accumulated Fund		180 9 11
1,506			£2,528 19 1

1950	INCOME.	£ s. d.
£		
1,191	By **Membership Subscriptions**	1,939 7 0
104	,, **Entrance Fees**	226 5 0
61	,, **Donations**	138 0 7
150	,, **Library Subscriptions and Sale of Journals**	186 12 11
	,, **Sundry Receipts**	38 13 7
1,506		£2,528 19 1

BALANCE SHEET as at 30th September, 1951

BALANCE SHEET as at 30th September, 1951.

1950	*Capital and Reserves.*	£ s. d.	£ s. d.
	Accumulated Fund—		
199	Balance at 30th September, 1950	201 13 10	
	Add Excess of Income over Expenditure for the year to 30th		
3	September, 1951	180 9 11	
202			382 3 9
	Compounded Subscriptions		
104	**Reserve Account**		381 0 0
100	**Subscriptions Reserve Account**		200 0 0
406	Total of Capital and Reserves		963 3 9
	Current Liabilities.		
67	**Subscriptions paid in advance**	121 6 5	
184	**Sundry Creditors**	71 0 6	
251			192 6 11
657			£1,155 10 8

1950	*Fixed Assets.*	£ s. d.	£ s. d.
	Furniture and Equipment—		
152	Balance at 30th September, 1951, at cost	152 9 6	
—	*Less* Items written off	26 7 0	
		126 2 6	
46	*Less* Depreciation to date	66 2 6	
106			60 0 0
	Library—		
110	Balance at 30th September, 1951, at cost	194 9 0	
84	Additions during year at cost	72 8 3	
194		266 17 3	
80	*Less* Depreciation to date	126 17 3	
114			140 0 0
220	Total of fixed assets		200 0 0
	Current Assets.		
22	**Sundry Debtors**	31 19 6	
—	**Stock of Postcards**	10 7 2	
34	**Payments made in Advance**	27 0 0	
134	**Establishment Fund Deposit Account**	459 0 0	
246	**Cash at Bank Current Account**	397 19 4	
1	**Cash in Hand**	29 4 8	
437			955 10 8
657			£1,155 10 8

Certified to be a true copy—

A. C. CLARKE, A. V. CLEAVER } *Members of the Council.*

L. J. CARTER, *Secretary.*

REPORT OF THE AUDITOR TO THE MEMBERS OF THE BRITISH INTERPLANETARY SOCIETY

I have obtained all the information and explanations which to the best of my knowledge and belief were necessary for the purposes of my audit. In my opinion proper books of account have been kept by the Society so far as appears from my examination of those books. I have examined the above Balance Sheet and annexed Income and Expenditure Account which are in agreement with the books of account. In my opinion and to the best of my information and according to the explanations given to me, the said accounts give the information required by the Companies Act, 1948, in the manner so required, and the Balance Sheet gives a true and fair view of the state of the Society's affairs as at 30th September, 1951, and the Income and Expenditure Account gives a true and fair view of the surplus of income over expenditure for the year ended on that date.

35, Brian Avenue,
Sanderstead, Surrey.
5th November, 1951.

T. W. WOODS,
Incorporated Accountant.

SECOND INTERNATIONAL ASTRONAUTICAL CONGRESS, LONDON, 1951

In the B.I.S. *Annual Report* for 1950, an account was given of the proceedings at the First International Astronautical Congress held in Paris from 30th September to 2nd October of that year. It was decided at that first Congress to hold a second one in London in 1951; the B.I.S., at the request of the other national groups, undertook to organise this, and also to co-ordinate the suggestions of all societies regarding the Constitution of a proposed International Astronautical Federation.

This latter body was to be an association of autonomous national astronautical societies, dedicated to the advancement of space-flight. A Provisional Committee, composed of delegates from the societies attending at Paris and having Dr. Eugen Sänger as its President, was set up; the duty of this Committee was to consider the proposed I.A.F. in greater detail, with a view to its formal inauguration in London the following year.

It was also agreed in Paris that the London Congress should include a technical session, at which scientific papers would be read.

Following the return of its delegates to London, the B.I.S. held discussions on all the above matters, both in Council and at a General Meeting of the Society (see *Journal*, January, 1951), and then proceeded with the arrangements on the agreed lines. It is gratifying to be able to report now that the London Congress took place very successfully, exactly as planned at Paris; what follows is a detailed record of the proceedings.

Preliminaries

First, it seems worthwhile to describe some of the events of the year intervening between the Paris and London Congresses, both for their own interest and as a guide for the organising of future Congresses.

The B.I.S., on 9th December, 1950, circulated a provisional programme for the London Congress. This was sent to all the societies represented at Paris, and to all others thought likely to be interested. It conformed almost exactly to the programme which finally took place, and the opportunity was taken to remind the other societies that they had promised to submit proposals for the I.A.F. Constitution by January 1st, 1951, also to invite them to nominate lecturers for the technical sessions of the Congress.

It is to be regretted that many of these preliminary discussions, by correspondence, occupied a longer time than was hoped; replies from some societies were long delayed, with the result that it was not until May, 1951, that the B.I.S. was able to circulate a full draft Constitution for the I.A.F., describing the proposals received from other societies and attempting a compromise between them. The exact composition of the lecture programme was also in some doubt until just before the Congress opened, and a matter of particular concern was the question of the participation (or otherwise) in all the proceedings of the American Rocket Society and other U.S. groups. These had not been in attendance in Paris, and it was therefore with the greatest pleasure that the news was received, during July, 1951, that they intended to give the London Congress their full support.

The final comments of other societies, on the I.A.F. Constitution, were also somewhat delayed and incomplete; like the original proposals, they indicated little disagreement on broad general principles, but quite a variety of views on questions of detail.

The foregoing observations are not made in any spirit of recrimination, but simply with a view to helping the I.A.F. as much as possible during its early formative and difficult years. During this period, and especially because of the current international situation, it is obvious that personal contacts between the individuals concerned cannot be as close and frequent as would be desirable. This makes it essential that the representatives of all the associated national societies should co-operate, in an atmosphere of trust and goodwill, and especially by the prompt and frequent exchange of letters.

With this background, and after the despatch from the B.I.S. of a number of final circulars specifying last-minute arrangements, the stage was set for the 1951 Congress. Hotel accommodation in London was found for all visiting delegates who had requested it; this was not easy in this Festival Year, and it may be that the results, in some cases, left something to be desired. However, all concerned seemed to feel that all that mattered was that they were in London for the Congress, wherever they were staying, and it is hoped and believed that most delegates, at any rate, were reasonably comfortable. During the week-end of 1st–2nd September, B.I.S. Council Members met those delegates who had advised us of their exact time and method of arrival; Press representatives were much in evidence at the London Continental termini on those days, and some of our more distinguished astronautical visitors appeared surprised (and, with the obvious reservation, gratified !) to discover the extent of the interest in interplanetary flight shown by British newspapers.

Following these two days, during which old friendships were renewed, and new ones formed, the Congress opened officially on Monday, 3rd September, and lasted until Saturday, 8th September.

3rd September

The proceedings began with a reception, held from 10 a.m. to noon, at St. Ermin's Hotel, adjoining Caxton Hall. Refreshments were served and delegates were issued with badges and information on final arrangements. The object of this function was for delegates to meet one another and become better acquainted in an informal atmosphere well-suited to preliminary and unofficial discussions. The Press was also invited, and turned up in force; the newspapers that evening and the following day were full of the results of all the shorthand notebooks and cameras so much in evidence in the St. Ermin's Ballroom in the morning. The venue of this reception, however, was large enough to permit all these varied activities to proceed without mutual interference, and it is thought to have fulfilled admirably its intended purpose.

This would seem an appropriate place to insert a complete list of all the delegates attending the Congress from abroad; it is hoped that the list *is* complete, but very probably there are some omissions, for which the apologies of the B.I.S. are tendered in advance. It should be explained that not all the

E. Burgess, Dr. E. Sänger, K. W. Gatland and Dr. Bredt engaged in discussion

A. Hjertstrand, F. C. Durant, K. Schutte, E. Sänger and G. Partel
at the opening reception.

delegates attended on every day, also that some of them were members of more than one national society (e.g., several were members of the B.I.S.); they are listed below against their country of origin.

Argentina - -	T. Tabanera.
Austria - - -	F. Hecht, B. Langenecker.
France - - -	A. Ananoff, J. Galavardin.
Germany - -	F. J. Adamczewski, — Bödewadt, I. Bredt, — Haus, H. Hoeppner, F. K. Jungklaass, E. von Khuon-Wildegg, H. Koelle, H. Kuhme, W. H. Linke, G. Loeser, R. Merten, H. Möltgen, R. Nebel, H. Oberth, H. H. Oerke, A. Pullenberg, E. Sänger, L. Schmidt, K. Schutte, E. Sellner, L. Sunder-Plassmann.
Holland - - -	J. H. Houtman.
Italy - - -	G. P. Casiraghi, A. Eula, G. Partel.
Spain - - -	T. Mur.
Sweden - - -	A. Hjertstrand.
Switzerland -	J. Stemmer.
U.S.A. - - -	F. C. Durant, D. Elliott, A. G. Haley, C. J. Pierce, E. V. Sawyer, J. G. Vaeth.

Working Sessions

These were held in the Kent Room of Caxton Hall (Westminster), on 3rd September, afternoon, and 4th September, morning and afternoon. On each day (as also during the technical sessions on 6th-8th September), a separate room was also available to delegates for conversations, Press interviews, etc.; in this, a display of astronautical books and periodical literature, and Press photographs taken during the Congress, was always on view.

Since the object of these working sessions was the discussion of the I.A.F., its Constitution and activities, inter-society co-operation, and other purely business matters, they were not open to the Press or the general public. Accredited members of the visiting societies and the B.I.S. were welcomed as observers, but not more than two delegates from each society represented were recognised as spokesmen in the discussions. After Mr. Arthur C. Clarke (Chairman of Council, B.I.S.) had opened the proceedings, the Chair was taken at all the Working Sessions by Dr. Eugen Sänger, as President of the Provisional Committee of the I.A.F. The spokesmen-delegates of the participating societies presented their credentials, and also gave certain other information (e.g., on society membership), as below:—

Argentina. Prof. T. Tabanera. *Sociedad Argentina Interplanetaria* (S.A.I.), membership 22.

Austria. Prof. F. Hecht, deputising for Dr. Rückert, who was unfortunately prevented from attending by an accident. *Oesterreichische Gesellschaft für Weltraumforschung* (O.G.f.W.), membership about 50.

France. M. A. Ananoff. *Groupement Astronautique Francais* (G.A.F.), membership 210.

Germany. Although it was announced just before the Congress that the various German groups had agreed to amalgamate, the final arrangements for this merger were not completed in time for it to be possible for a single delegation to attend. The two largest German groups were therefore represented as follows:—
Dr. G. Loeser and Herr H. H. Koelle. *Gesellschaft für Weltraumforschung*, Stuttgart (SE-G.f.W.), membership 416.
Herr F. K. Jungklaass and Ing. A. Pullenberg. *Gessellschaft für Weltraumforschung*, Hamburg (NW-G.f.W.), membership 170.

Italy. Prof. G. P. Casiraghi and Capt. G. Partel. *Associazzioni Italiana Razzi* (A.I.R.), membership 35. (This society, however, has only just been formed).

Spain. Senor T. Mur. *Asociacion Espanola de Astronautica* (A.E.A.), membership 80.

Sweden. Ing. A. Hjertstrand. *Svenska Interplanetarisk Selskap* (S.I.S.), membership about 60.

Switzerland. Ing. J. Stemmer. Society in process of organisation, with nucleus of 15 active members.

U.K. Mr. A. C. Clarke and Mr. A. V. Cleaver. *British Interplanetary Society* (B.I.S.), membership 1,409.

U.S.A. The various American societies were represented as follows:—
Mr. A. G. Haley and Lt.Cmdr. F. C. Durant. *American Rocket Society* (A.R.S.), membership 1,461.
Mr. E. V. Sawyer. *Pacific Rocket Society* (P.R.S.), membership 205.
Mr. Sawyer also represented the *Chicago Rocket Society* (C.R.S., membership 135), the *Detroit Rocket Society* (D.R.S., membership 85), and the *Reaction Research Society* (R.R.S., membership 70), while Mr. D. Elliott also attended on behalf of the R.R.S.

Copies of the official minutes of the Working Sessions have, of course, been sent to all the societies listed above. Limitations of space prevent the presentation here of more than the bare outlines of the proceedings, but the following points cover all the main action taken:—

(i) The International Astronautical Federation (I.A.F.) was formally inaugurated on 4th September, 1951. Its member societies comprise all those listed above, with the exception of the Chicago Rocket Society, which signified (through Mr. Sawyer) that it did not wish

to join this year but would re-consider its position in 1952. All other astronautical societies are, of course, also eligible to apply for membership as from this date, if they so wish.

(ii) Dr. Eugen Sänger was unanimously elected the first President of the I.A.F., with Dr. G. Loeser (G.f.W.) and Mr. A. G. Haley (A.R.S.) as Vice-Presidents. The Council of the I.A.F. will consist of one representative each from all the member societies, and will be responsible for decisions on all future action to be taken by the I.A.F. The member societies will retain their autonomy, with the right to withdraw from the I.A.F. if they wish. Ing. J. Stemmer was appointed Honorary Secretary of the I.A.F., charged with the duty of providing a central address in Switzerland, and holding its archives, for the new body.

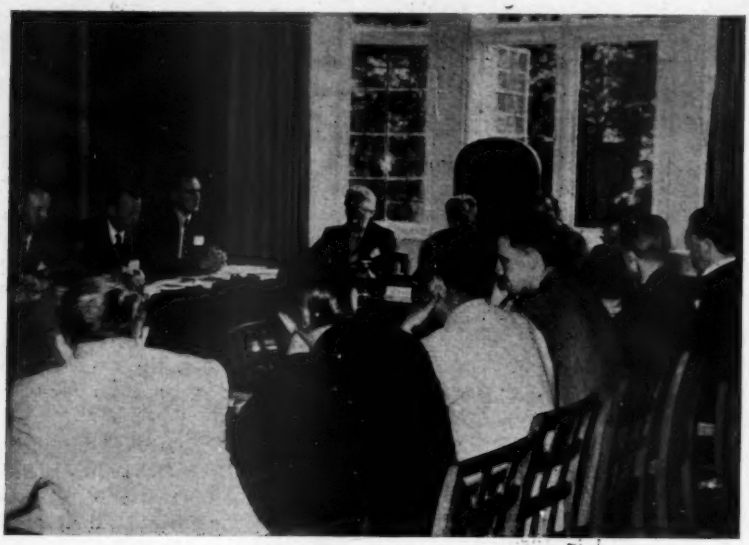
(iii) The I.A.F. will endeavour to continue to hold annual Astronautical Congresses, and the SE–G.f.W. (or its successor, the amalgamated all-German society) was requested to arrange for the third one to be held in Germany (probably in Stuttgart) in September, 1952.

(iv) The final details of the I.A.F. Constitution will be worked out during the coming year, under the supervision of the two Vice-Presidents, who will arrange for details to be circulated to all the member societies for consideration and comment. The Constitution will then be ratified in 1952.

Most of the clauses contained in the B.I.S. draft Constitution proved acceptable to all societies, but prolonged discussion took place on the relative voting power to be given to different societies on the I.A.F. Council. Briefly, the position was that the smaller societies were naturally anxious to avoid being out-voted by the larger ones, while the larger ones in turn were, equally naturally, anxious to be accorded some recognition of their greater responsibilities and influence. A special difficulty existed in countries where several societies, large and small, operated side by side. In view of the forthcoming amalgamation of all the German groups, this reduces in future practice to the case of the U.S.A.

Anticipating these difficulties, the B.I.S., in its draft proposals and during the actual Working Sessions of the Congress, suggested a number of compromise solutions. None of these, however, proved acceptable to all concerned, and in the time available it proved impossible to reach a final solution. At the London Congress, it had been agreed to adopt the system of "One society—one vote," and it was amicably decided to retain this for one more year, with details of a final system to be worked out in the meantime for discussion at the 1952 Congress.

Discussion also took place on certain other activities to be undertaken in the name of the I.A.F., which had first been suggested at Paris in 1950, and on which some progress had already been made—e.g., improved interchange of



FIRST WORKING SESSION OF THE CONGRESS

Seated round the table (moving clockwise) are E. V. Sawyer, F. C. Durant, L. J. Carter, H. Oberth, E. Sänger, A. C. Clarke, A. V. Cleaver, A. Hjertstrand, K. F. Jungklaass, H. H. Koelle, G. Loeser, A. Ananoff, and F. Hecht

Monsieur A. Ananoff presents Mr. Cleaver with the medal of the Aero Club de France for his work in connection with the Congress

publications and information between societies, standardisation of nomenclature, etc. It was agreed that further efforts should be made in these directions, and there was also a widespread feeling of support for the view of the SE-G.f.W. that the I.A.F. should aim eventually to control its own research institute—though such an ambitious plan could not be rushed, and little could be done towards it at this stage.

Other interesting events occurring during the Working Sessions were:—

On 3rd September, M. Ananoff presented Mr. Cleaver with a medal from the French Aero Club (within which the G.A.F. operates), in recognition of his preparatory work for the London Congress and on the draft I.A.F. Constitution. Mr. Cleaver, in thanking M. Ananoff, said that he was very proud to receive this honour, which he accepted with much pleasure in the understanding that it was really a recognition, not only of his own efforts, but also those of his colleagues in the B.I.S.

Information was exchanged on the position regarding other societies unable to be represented in London. The B.I.S. were able to report that the Danish society, which Dr. Loeser thought now had about 45 members, was desirous of joining the I.A.F. Their delegate, Lt. E. Birch Andersen, had unfortunately been prevented, almost at the last moment, from attending, because of family illness. The society which had just been formed in Norway also wished to support the I.A.F. Although unable to send a delegate to London, they presented the I.A.F. with a splendid silver gavel, for use at its meetings; this generous gift was accepted with much gratitude.

Lt.-Cmdr. Durant thought the Canadian Rocket Society now had about 100 interested members, and would probably become more active soon, while Dr. Loeser thought a group of similar size might soon arise in the Middle East, under the leadership of Ing. Fuellner in Cairo. No delegate knew of any recent activities on the part of the United States Rocket Society, though its Founder-President (Mr. R. L. Farnsworth) had sent a message of good wishes for the London Congress to the B.I.S.

Mr. Clarke reported that messages of goodwill had been received from M. Robert Esnault-Pelterie, the great French pioneer and Honorary Fellow of the B.I.S., and also from the B.I.S. North-Western Branch in Manchester. Ing. Bialoborski, of Poland, had expressed his regret at being unable to be present, as also had Ing. de Koningh of Holland. Although there were known to be many persons interested in astronautics in these two countries, no specifically astronautical societies were believed to exist in either.

Attempts had been made to send invitations to the London Congress to any groups which might exist inside the U.S.S.R., through the Russian Academy of Sciences. This had been done as a matter of courtesy, but only a bare acknowledgement had been forthcoming in reply, so the position remained unknown—as was also the case for the other countries East of the "Iron Curtain."

The total number of people present at each of the Working Sessions averaged about 50.

5th September

This day (Wednesday) was kept free, but the B.I.S. presented all delegates with tickets to the South Bank (Festival of Britain) Exhibition, and several B.I.S. Council Members accompanied a number of them on a visit there. Other delegates, at the invitation of the 20th-Century Fox Co., attended a trade preview of a new film ("The Day the Earth Stood Still") having an interplanetary theme.

These brief social interludes, like the great many impromptu dinners, lunches, and other meetings which took place during the Congress, played a pleasant and important part in helping to forge international bonds of goodwill between the various delegates.

Technical Sessions

These were held during both the mornings and afternoons of 6th and 7th September, in the Great Hall of Caxton Hall. All the sessions were very well attended, being, of course, open both to Press representatives and the general public.

The British contributions to this programme of lectures were printed in full in the November, 1951, issue of the B.I.S. Journal, together with summaries in English of the papers given by speakers from abroad. Little remains to be done in this Report, therefore, beyond summarising the programme as below, but one outstanding point should be noted. This was the unanimity of opinion shown by the technical representatives from all countries regarding the significance of the "Earth-Satellite-Vehicle." There had been universal support in Paris in 1950 for the choice of this subject as a theme to connect all the papers of the technical sessions, and this was reflected in the agreement shown between all the lecturers that it represents the first and essential task in the conquest of space. All the contributors believed that interplanetary flight must, or at least should, involve refuelling at some sort of orbital base, whether it be a "space-station," in the usually accepted sense, or simply a rendezvous position for a fleet of tanker rockets.

The 1951 London Congress may well form a landmark in astronautical history, not only for its inauguration of the I.A.F., but also for this evidence which it afforded of widespread fundamental agreement on the methods capable of achieving interplanetary flight.

The full list of papers presented was as follows:—

September 6th, 1951.

Thursday Morning, 10 *a.m. to* 1 *p.m.* (Dr. L. R. Shepherd in the Chair).

"The Artificial Satellite," an Introduction by Dr. L. R. Shepherd (B.I.S.).

"The Importance of Satellite Vehicles in Interplanetary Flights," by Dr. W. von Braun (A.R.S.), read by Lt.-Commander F. C. Durant (A.R.S.).

"Interplanetary Travel between Satellite Orbits," by Professor L. Spitzer (B.I.S.), read by A. V. Cleaver (B.I.S.).

"Foundation of the Space Station," by Ing. G. von Pirquet (O.G.f.W.), read (in German) by Professor F. Hecht (O.G.f.W.).

Thursday Afternoon, 2.30 *to* 5.30 *p.m.* (Ing. A. Hjertstrand in the Chair).

"Biological Problems of the Satellite Vehicle," by Medecin-General Pierre Bergeret, read by Commandant Jean Gallavardin (G.A.F.) (in French).

"Descent from Satellite Orbits using Aerodynamic Braking," by T. R. F. Nonweiler, B.Sc. (B.I.S.).

"The Optimum Satellite Freight Rocket," by Ing. H. Hoeppner (G.f.W.) (in German).

"The Start, Return and Landing of an Optimum Satellite Rocket," by Dipl. Ing. H. Kuhme (G.f.W.) (in German).

September 7th, 1951.

Friday Morning, 10 *a.m. to* 1 *p.m.* (Lt.-Cmdr. F. C. Durant in the Chair).

"Design Problems of the Space Station," by H. H. Koelle (G.f.W.).

"Meteor Hazards to Space Stations," by M. W. Ovenden, B.Sc. (B.I.S.).

"The Optimum Orbit for Radar Tracking," by Dr. R. Merten (G.f.W.) (in German).

"Landing of Space Craft," by E. V. Sawyer (P.R.S.). (Mr. Sawyer also read a short paper, "The Space Station as an Astronomical Observatory Site," by A. L. Joquel II (R.R.S.).

Friday Afternoon, 2.30 *p.m. to* 5.30 *p.m.* (Dr. G. Loeser in the Chair).

"Minimum Satellite Vehicles," by K. W. Gatland, A. Kunesch and A. E. Dixon (all B.I.S.).

"Orbital Rendezvous Problems," by R. A. Smith (B.I.S.).

"Construction—Proposition Space Station," by Ing. A. Pullenberg (G.f.W.) (in German).

"How a Space Station might be Constructed," by Ing. R. Nebel (in German).

Short printed English summaries of many of the above papers were available beforehand to delegates and Press representatives, and in the case of those papers read in German and French, the English summaries were read out immediately following the lecture.

8th September

On this Saturday afternoon a public meeting was held in the Great Hall of Caxton Hall, with a view to publicising the results of the Congress and the ideas of the various delegations on the subject of interplanetary flight. It was attended by some 400 persons, and an interesting feature was the display of the exhibits on astronautics prepared by the *Daily Express*, in collaboration with the B.I.S., for their "50 Years of Flying" show at Hendon (held on 19th-21st July—see September, 1951, *Journal*).

Mr. A. C. Clarke, from the Chair, made a statement on the Congress, its background, purpose, and results, culminating in the foundation of the I.A.F. He said how pleased the B.I.S. and their overseas visitors had been at the

The concluding Dinner of the Congress, St. Ermin's Hotel, Saturday, 8th September, 1951
The Guests of Honour were Dr. I. Bredt, Dr. E. Sänger and Professor H. Oberth.

SEATING PLAN

HEAD TABLE (*left to right*):—T. Tabanera, T. Mur, F. C. Durant, G. Loeser, I. Bredt, E. Sänger, A. C. Clarke, H. Oberth, A. V. Cleaver, A. G. Haley, G. Casiraghi, Mrs. Hjertstrand, A. Hjertstrand.

TABLE 1 (*nearest camera, moving anti-clockwise*):—J. Houtman, Mrs. Houtman, H. Kühme, O. W. Neumark, G. Partel.
E. V. Khuon-Wildegg, G. Eula, N. R. Nicoll, Mrs. Greenlees, H. Greenlees, —. Garrus, G. E. Mallaber, K. W. Gatland.

TABLE 2:—A. E. Dixon, A. E. Slater, Mrs. Smith, R. A. Smith, Mrs. M. E. Patchett, H. E. Ross, A. L. Helm, L. Yoxall.
Mrs. V. Reid, L. A. Blanckensee, Miss I. Seitler, Mrs. I. Berrer, E. Roeseger, A. H. Smith, A. Pullenberg, W. H. Linke.

TABLE 3:— —. de Johasz, A. Housden, L. Schmidt, F. J. Adamczewski, L. Sunder-Plassmann, N. F. Gaythorpe, R. Nebel, G. R. Ramsden.
R. Wilkins, , K. Schutte, J. Stemmer, G. V. E. Thompson, H. Hoeppner, B. Langenecker, T. Hoare.

TABLE 4:—W. N. Neat, Mrs. Shepherd, L. R. Shepherd, Press, J. Humphries, Press, Mrs. Koelle, H. H. Koelle.
L. J. Carter, E. Sellner, W. H. Gillings, R. Merten, E. Burgess, Press, Mrs. Pierce, C. J. Pierce.

Congress having been honoured by the presence of that great pioneer of astronautics, Professor Hermann Oberth. Perhaps more than any other man, Professor Oberth could fairly be described as the father of astronautics, and he called upon him to address the meeting.

Professor Oberth, speaking in German, expressed his pleasure at attending the Congress and at its results, and referred to the necessity of international co-operation for the peaceful realisation of space-flight. Dr. Loeser, from the platform, translated his speech into English.

Mr. Clarke then introduced Dr. Sänger, as President of the I.A.F. Dr. Sänger said he was most gratified by the foundation of this Federation and spoke of his hopes for the part it might play in the development of interplanetary flight. He also supported the opinions expressed by Mr. Clarke in his introduction, regarding the motives behind this development; they were the same as those responsible for all other human achievement, in the fields of discovery and invention, and it was natural for man to pass from the study of earlier forms of transport to that of the spaceship.

Mr. Clarke then introduced, in turn: Professor Hecht, Professor Tabanera, Dr. Shepherd, Dr. Loeser, Herr Jungklaass, Professor Casiraghi, Senor Mur, Ing. Hjertstrand, Ing. Stemmer, Lt.-Cmdr. Durant, and Mr. Sawyer. All these speakers variously dealt with such matters as the position of astronautics in their respective countries, their views on interplanetary flight, and the highlights of papers presented under their sponsorship at the preceding technical sessions.

In particular, Professor Hecht referred to the early realisation of the vital importance of the space-station refuelling technique, as a means of rendering interplanetary travel practicable, on the part of Baron Ing. Guido von Pirquet—the great Austrian pioneer who is now one of our six Honorary Fellows. Dr. Loeser spoke of his hopes for an International Astronautical Research Institute, for the peaceful realisation of space-flight, to be administered by the I.A.F. (See B.I.S. *Journal*, July, 1951.) Professor Casiraghi said the new Italian society was too young to have done much yet, but that it had the advantage of the active membership of many eminent technical men, including Gen. Professor G. A. Crocco. Lt.-Cmdr. Durant thought that the next few decades would certainly see the establishment of "Earth-Satellite-Vehicles" of one sort or another, and this should lead, gradually and inevitably, to interplanetary travel; that was the view of Dr. von Braun, whose paper he had read at the Congress. It was also his own, and that of the A.R.S. Our own Dr. Shepherd gave an excellent summary of the B.I.S. contributions to the Technical Sessions, and showed how they combined to indicate the probable lines along which space-flight would finally be achieved.

Mr. Clarke declared the meeting closed at 5.30 p.m., and with it the formal business of the Second International Astronautical Congress. The delegates then dispersed, to re-assemble in the evening for a less formal conclusion to the proceedings.

This was a dinner, held at the St. Ermin's Hotel, and proved to be an extremely happy and pleasant occasion for all those present. It lasted from 7 p.m. until about 11.30 p.m., the delegates remaining after dinner to drink and talk, and make their farewells, in a friendly atmosphere of informality. At the dinner itself, Mr. Haley proposed a toast to the I.A.F., which was replied

to by Dr. Sänger. Mr. Clarke proposed the health of the visitors to the B.I.S., to which Dr. Loeser responded, and Professor Casiraghi (in a typically witty speech) toasted the B.I.S. In thanking Professor Casiraghi, Mr. Cleaver said the preparations for the Congress had involved a lot of hard work, but we all felt it was well worth while. The dinner was attended by 76 persons, the overseas visitors as guests of the B.I.S.

Acknowledgements

In concluding this report, it is only right that some tribute should be paid to those individuals and organisations who helped to make the Congress so successful.

Almost all the arrangements for the Congress were handled by Mr. Clarke (Chairman), Mr. Carter (Secretary), and Mr. Cleaver, with Dr. Shepherd (Technical Director) carrying responsibility for planning the lecture programme. Without exception, however, great assistance was also given (especially during the Congress itself) by all the Members of Council (Messrs. Burgess, Gatland, Gillings, Humphries, Ross, Smith, Thompson, and Dr. Slater), and by several other volunteer B.I.S. members. Among these latter, special mention should be made of Messrs. Kunesch, Dixon, Nicoll, Rotheram, Fears, Helm and Mrs. Patchett. Mr. Helm, both before and during the Congress, gave invaluable help in the matter of German-English translation; it must also be recorded that, during the Congress, the similar work of Herr Koelle (of the G.f.W.) was also greatly appreciated.

Although he was prevented by absence abroad from actually attending the Congress, the services of Mr. Charles Gibbs-Smith as Honorary Press Officer were invaluable. On his advice, a folder of data on the Congress was prepared, and issued to the Press during August; he also suggested all the general arrangements made for handling the Press during the Congress. The folder of Press releases issued beforehand consisted of the full Congress programme, literature on the B.I.S., and four short statements prepared by Messrs. Clarke and Cleaver ("The Aims of the Congress," "Interplanetary Flight—How, When, Why, and Where?" "The Earth-Satellite-Vehicle—what it will be and what it can do," and "Congress Personalities").

As a result, we can take pleasure in reporting that the Congress received a very good press, and it is not out of place here to acknowledge our appreciation of the generally fair and accurate treatment accorded to the event. At the time of writing, some 400 Press references have been seen, and with a very few inevitable exceptions tending towards the sensational, the facetious, or just plain incorrect, they were most satisfactory. The astronautical movement, especially in Great Britain, can only benefit as a result. The interest shown was most widespread, resulting in many editorials, and on the evening of Saturday, September 8th, the B.B.C. included an interview with Lt.-Cmdr. Durant and Mr. Gatland in their "In Town Tonight" feature.

Our thanks are due to *The Daily Express* for the loan of their astronautical exhibit on 8th September, and for the arrangements they made for its delivery and erection, also to Messrs. H. K. Lewis, the famous scientific booksellers of Gower Street, for their provision of a bookstand, on all days, displaying astronautical literature.

LIST OF SOCIETIES INTERESTED IN SPACE-FLIGHT

For the interest and use of our overseas readers, in particular, a list of addresses of astronautical societies is appended below.

Argentina.	*Sociedad Argentina Interplanetaria, Tucuman 950, Buenos Aires.
Austria.	*Osterreichische Gesellschaft für Weltraumforschung, Innsbruck, Postfach 67.
Canada.	Canadian Rocket Society, 58, Hilton Avenue, Toronto 10, Ontario.
Denmark.	†Dansk Selskab for Rumfarts-Forskning, 52, Svanemollevej, Copenhagen.
France.	*Groupement Astronautique Francais, L'Aeronautique Club de France, 37, Rue Lafayette, Paris IX.
Germany.	*Gesellschaft für Weltraumforschung, Langobardenstrasse 15, Stuttgart-Zuffenhausen. *G.f.W.—NW, Schliessfach 509, Göttingen (20b). †G.f.W—SW, Falkstrasse 77, Frankfurt am Main.
Italy.	*Associazzioni Italiana Razzi, c/o AIDA, Piazza S. Bernardo 101, Rome.
Norway.	†Norsk Interplanetarisk Selskap, Mogens Thorsens gate 9, Oslo.
Spain.	*Associacion Espanola de Astronautica, Alcala 155, Madrid.
Sweden.	*Svensk Interplanetarisk Selskap, Engelbrektsgatan 16 III, Stockholm.
Switzerland.	*c/o Ing. J. Stemmer, Postfach Baden, Baden.
U.K.	*British Interplanetary Society, 157, Friary Road, London, S.E.15.
U.S.A.	*American Rocket Society, 29, West 39th Street, New York 18. Chicago Rocket Society, 10630, S. St. Louis Avenue, Chicago, Illinois. *Detroit Rocket Society, 682, S. Waterman Avenue, Detroit, Michigan. *Pacific Rocket Society, 1128, Fair Oaks Avenue, S. Pasadena, California. *Reaction Research Society, 3262, Castera Avenue, Glendale 8, California. United States Rocket Society, 469, Duane Street, Glen Ellyn, Illinois.

* Indicates that the society is a founder-member of the I.A.F., having been represented at the London Congress.

† Indicates that the society is expected to join the I.A.F.

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Donations totalling £138 0s. 7d. were received from 213 members during the year and are now gratefully acknowledged.

A list of the donors of amounts of 10s. and over is printed below.

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ASTRONAUTICAL POSTCARDS

A limited number of the postcards issued as souvenirs of the Second International Congress on Astronautics are still available. They depict the following scenes:—

(*a*) "The German A4 Rocket" (*photo British Interplanetary Society*).

(*b*) "View of the Earth at 60 miles altitude" (*photo U.S. Navy*).

(c) "Building a Space Station" (drawing by R. A. Smith from *The Exploration of Space*, Temple Press, Ltd.).

(*d*) "The Lunar Landscape" (*photo Lick Observatory*).

(e) "The Rocket in a Lunar Crater" (*Scene from Destination Moon*).

(*f*) "Imaginary view of Saturn fromits Nearest Satellite" (from a painting by Chesley Bonestell in *The Conquest of Space*, Sidgwick & Jackson, Ltd.).

The postcards are available at 2s. per set, post free, from the Secretary at—
157, Friary Road, London, S.E.15.